

An Engineering Study of Onboard Checkout Techniques

A GUIDE TO ONBOARD CHECKOUT
VOLUME I: GUIDANCE, NAVIGATION AND CONTROL

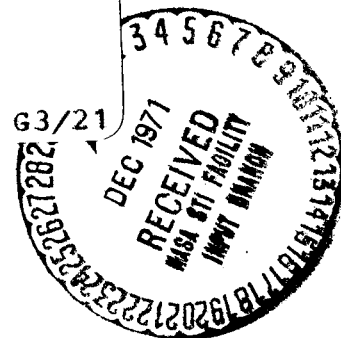
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An Engineering Study of Onboard Checkout Techniques

**A GUIDE TO ONBOARD CHECKOUT
VOLUME I: GUIDANCE, NAVIGATION AND CONTROL**

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FOREWORD

This is one of a set of seven reports, each one describing the results, for a particular subsystem, of a study titled "An Engineering Study of Onboard Checkout Techniques." Under the general title of "A Guide to Onboard Checkout," the reports are as follows.

<u>Volume</u>	<u>IBM Number</u>	<u>Subsystem</u>
I	71W-00308	Guidance, Navigation and Control
II	71W-00309	Environmental Control and Life Support
III	71W-00310	Electrical Power
IV	71W-00311	Propulsion
V	71W-00312	Data Management
VI	71W-00313	Structures/Mechanical
VII	71W-00314	R.F. Communications

This set of guides was prepared from the results of a nine month "Engineering Study of Onboard Checkout Techniques" (NAS9-11189) performed under NASA contract by the IBM Federal Systems Division at its Space Systems facility in Huntsville, Alabama, with the support of the McDonnell Douglas Astronautics Company Western Division, Huntington Beach, California.

Technical monitor for the study was Mr. L. Marion Pringle, Jr. of the NASA Manned Spacecraft Center. The guidance and support given to the study by him and by other NASA personnel are gratefully acknowledged.

Section 1

INTRODUCTION

1.1 OBJECTIVE

With the advent of large scale aerospace systems, designers have recognized the importance of specifying and meeting design requirements additional to the classical functional and environmental requirements. These "additional" requirements include producibility, safety, reliability, quality, and maintainability. These criteria have been identified, grown into prominence, and become disciplines in their own right. Presently, it is inconceivable that any aerospace system/equipment design requirements would be formulated without consideration of these criteria.

The complexity, sophistication and duration of future manned space missions demand that still another criterion needs to be considered in the formulation of system/equipment requirements. The concept of "checkoutability" denotes the adaptability of a system, subsystem, or equipment to a controlled checkout process. As with other requirements, it should also apply from the time of early design concept formulation.

The results of "An Engineering Study of Onboard Checkout Techniques" and other studies indicate that for an extended space mission onboard checkout is mandatory and applicable to all subsystems of the space system. In order to use it effectively, "checkoutability" should be incorporated into the design of each subsystem, beginning with initial performance requirements.

Conferences with researchers, system engineers and subsystem specialists in the course of the basic Onboard Checkout Techniques Study revealed an extensive interest in the idea of autonomous onboard checkout. Designers are motivated to incorporate "checkoutability" into their subsystem designs but express a need for information and guidance that will enable them to do so efficiently.

It is the objective of this report to present the results of the basic study as they relate to one space subsystem to serve as a guide, by example, to those who in the future need to implement onboard checkout in a similar subsystem. It is not practicable to formulate a firm set of instructions or recipes, because operational requirements, which vary widely among systems, normally determine the checkout philosophy. It is suggested that the reader study this report as a basis from which to build his own approach to "checkoutability."

1.2 BASIC STUDY SUMMARY

1.2.1 STUDY OBJECTIVE

The basic study was aimed at identification and evaluation of techniques for achieving the following capabilities in the operational Space Station/Base, under control of the Data Management System (DMS), with minimal crew intervention.

- Automated failure prediction and detection
- Automated fault isolation
- Failure correction
- Onboard electronic maintenance

1.2.2 STUDY BASELINE

The study started in July 1970. The system design baseline was established by the Space Station Phase B study results as achieved by the McDonnell-Douglas/IBM team, modified in accordance with technical direction from NASA-MSC. The overall system configuration was the 33-foot diameter, four-deck, 12-man station. Individual subsystem baseline descriptions are given in their respective "Guide to Onboard Checkout" reports.

1.2.3 STUDY TASKS

The basic study comprised five tasks. Primary emphasis was given to Task 1, Requirements Analysis and Concepts. This task established subsystem baseline descriptions and then analyzed them to determine their reliability/maintainability characteristics (criticality, failure modes and effects, maintenance concepts and line replaceable unit (LRU) definitions), checkout strategies, test definitions, and definitions of stimuli and measurements. After software preliminary designs were available, an analysis of checkout requirements on the DMS was performed.

A software task was performed to determine the software requirements dictated by the results of Task 1.

Task 3 was a study of onboard electronic maintenance requirements and recommendations of concepts to satisfy them. Supporting research and technology tasks leading to an onboard maintenance capability were identified. The study implementation plan and recommendations for implementing results of the study were developed in Task 4. The task final report also summarizes results of the study in all technical tasks.

Reliability, Task 5, was very limited in scope, resulting in an analysis of failure modes and effects in three Space Station subsystems, GN&C, DMS (computer group) and RF communications.

1.2.4 PREVIOUS REPORTS

Results of the basic study were reported by task in the following reports, under the general title of "An Engineering Study of Onboard Checkout Techniques, Final Report."

<u>IBM Number</u>	<u>Title</u>
71W-00111	Task 1: Requirements Analysis and Concepts
71W-00112	Task 2: Software
71W-00113	Task 3: Onboard Maintenance
71W-00114	Task 4: Summary and Recommendations
71W-00115	Task 5: Subsystem Level Failure Modes and Effects

Section 2

BASELINE SUBSYSTEM DESCRIPTION

2.1 GENERAL

This section describes the baseline Guidance, Navigation and Control (GN&C) subsystems which was analyzed to define onboard checkout requirements. In order to assess requirements for onboard checkout, descriptions at the subsystem level and the assembly level are required, as well as the major interfaces between subsystems.

The assembly level description for each of the subsystems (MSFC-DRL-160, Line Item 13) provided the primary working document for subsystem analysis. To reduce documentation, these documents have been incorporated by reference into this report, where applicable. Where no significant differences exist from the Phase B definition, this report contains a brief subsystem description and an identification of the referenced document containing the assembly level descriptions for that subsystem. Where significant differences do exist, the subsystem level description includes these changes. MSFC-DRL-160, Line Item 19, provided the major subsystem interface descriptions for analysis of integrated test requirements.

2.2 SUBSYSTEM LEVEL DESCRIPTION

The GN&C Subsystem provides the following functions:

- Orbit maintenance and change control
- Zero-g operation stabilization and attitude control
- Artificial-g operation dynamics and orientation control
- Navigation
- Command and monitor of rendezvous and docking
- Experiment pointing support and positioning control

The GN&C Subsystem senses and generates the commands and data for these functions, and the Propulsion Subsystem and a part of the GN&C Subsystem (the control moment gyros) generate the actuation forces and torques for executing these functions. The sensing of Space Station position and its relative range and range rate with respect to other spacecraft are provided through the guidance and navigation functions, and the sensing of the Space Station attitude and angular rates are provided through the controls function.

The Guidance, Navigation and Control Subsystem block diagram is shown in Figure 2-1. This subsystem consists of stellar-inertial sensors, horizon sensors, landmark trackers, range and range rate sensors, interface electronics, control logic and jet driver electronics, control moment gyros (CMGs) and associated electronics, and GN&C preprocessors.

The GN&C Subsystem must accommodate both the artificial-g and zero-g operations of the Space Station. In the artificial-g mode of operation, the GN&C Subsystem provides spin control and wobble damping of the rotating Space Station. The horizon crossing indicator sensor provides an attitude reference for the spin plane of the artificial-g mode. The attitude gyro package provides the rate signals necessary for the wobble damping function. In the zero-g mode of operation, the GN&C Subsystem provides autonomous navigation, rendezvous command, traffic control, automatic docking, and stabilization and control of the Space Station.

The autonomous navigation scheme utilizes the stellar inertial reference data and the automatic landmark tracker augmented with the drag accelerometer. The navigation is accomplished by automatically tracking known and unknown landmarks several times each orbit. The landmark tracker is similar in operation and mechanization to a gimbaled star tracker. The drag accelerometer accounts for anomalies due to Space Station orientation and docked module changes which contribute to navigation errors.

Both ground tracking and onboard subsystems will provide the navigation information for the first few years of the Space Station Program. The ground-generated data will be transmitted onboard for evaluation of the autonomous navigation system performance. As the confidence in autonomous operation is increased through this parallel operation, the ground tracking is to be phased out.

The rendezvous and traffic monitor functions are accomplished through the use of a communication/ranging system for ranges up to 1,000 nmi and with laser trackers within 110 nmi of the Space Station. The laser trackers are gimbal mounted to provide spherical coverage around the Space Station.

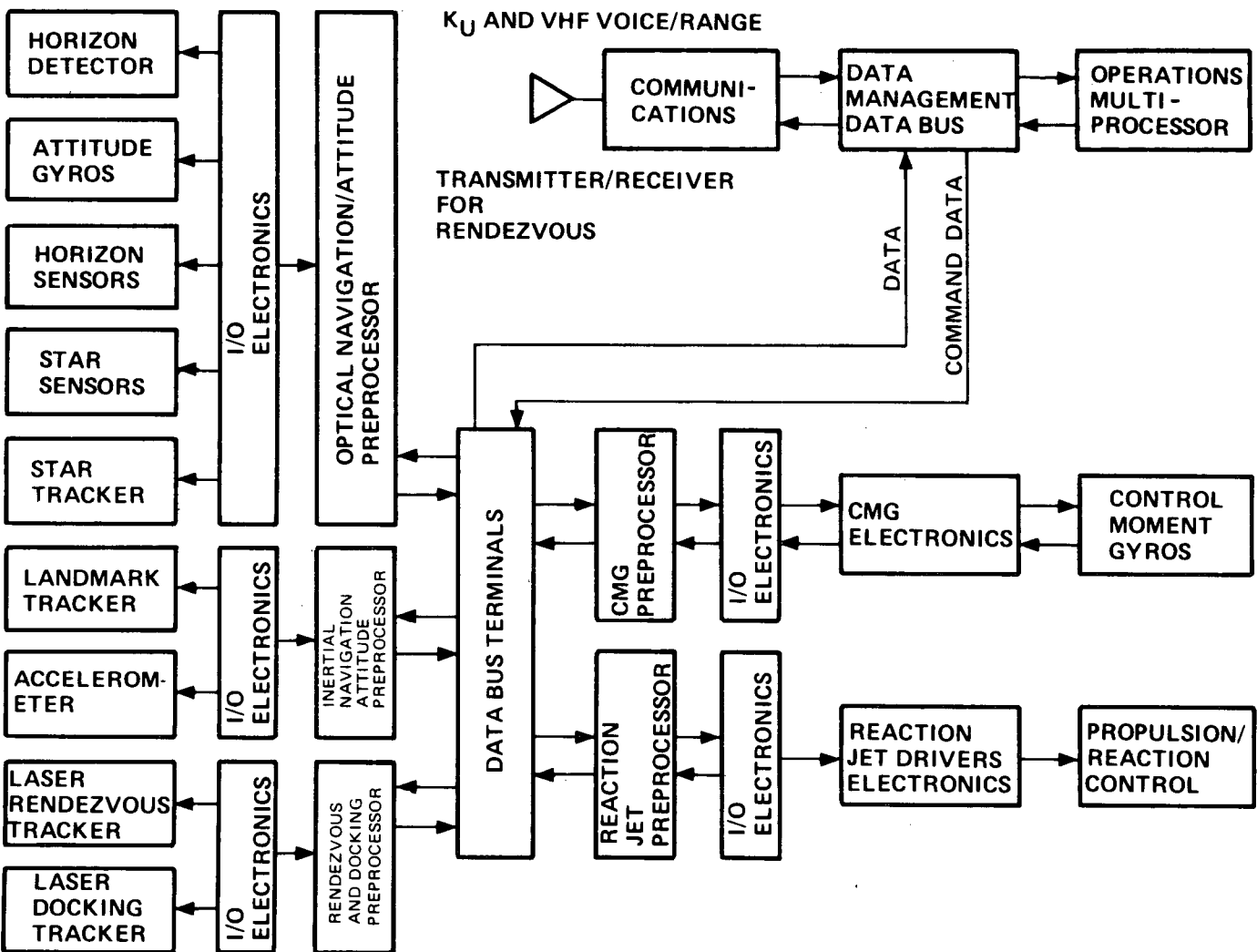


Figure 2-1. Guidance, Navigation, and Control Subsystem

For docking, each docking port is equipped with a laser docking transmitter/receiver to provide for automatic docking capability.

Attitude and rate information for attitude control and experiment support is determined by both Earth-centered and inertial orientations.

In all operating modes and orientations, the gyros provide the high-frequency rate and attitude information necessary to supplement the data from the stellar sensors and the horizon sensors. The horizon sensors are used for initial acquisition of the Earth-referenced coordinates. They also provide a coarse Earth reference which is used when fine pointing or inertial attitude information is not required.

A more accurate Earth-centered reference is obtained in the horizontal orientation through the use of the strapdown star sensors. The star sensors provide the long-term, drift-free inertial reference data while the gyros provide the short-term, high-frequency attitude and rate information. The passive star sensors are used while the Space Station is maintained in an Earth-centered orientation. The constant rotational rate required of the vehicle to maintain this type of orientation provides the scanning motion for the star sensors, which are completely passive and provide no tracking or scanning capability of their own. The sensors themselves provide inertial attitude data which is transformed into Earth-centered attitude information by use of the navigation parameters. By this method, both inertial attitude and Earth-centered attitude are derived from the passive star sensors while the vehicle is in the horizontal or other Earth-centered orientation. This Earth-centered orientation is considered to be the most responsive to experiment and subsystem requirements.

The gimballed star trackers are primarily utilized whenever the Space Station is required to maintain an inertial orientation. Because of the lack of angular rotation of the Space Station in this orientation, the sensors must provide their own tracking and scanning capability to acquire and track the desired reference stars.

Primary attitude control actuation is provided by control moment gyros (CMGs). A CMG configuration utilizing four double-gimballed CMGs, each having a momentum capacity of 1,100 ft-lb-sec, was selected for the isotope/Brayton-powered Space Station. Both high and low-thrust propulsion systems are utilized by the GN&C subsystem for CMG desaturation and backup attitude control capability. The reaction jet driver electronics provide the interface with the Propulsion Subsystem.

Computational capability is provided by the Space Station operations multiprocessor and the GN&C preprocessors. The preprocessors and the multiprocessor provide the link between the sensors, which are used to determine

the vehicle angular position, and the actuators, which are used to maintain or change the vehicle angular position. The GN&C preprocessors perform the necessary data formatting in addition to routine data processing for the individual sensor subsystem. The Space Station operations multiprocessor performs the data processing necessary for all guidance, navigation, and attitude control functions. The interface electronics assemblies control the flow of information from the sensors to the GN&C preprocessors and condition all sensor inputs to standardized levels. The output from the GN&C preprocessors is then routed to the operations multiprocessor via the Space Station Data Bus. The interface electronics assemblies perform a similar function for output information from the computer to the control actuators.

2.3 ASSEMBLY LEVEL DESCRIPTIONS

Descriptions of the GN&C Subsystem assemblies are provided in the Space Station MSFC-DRL-160, Line Item 13, Volume I, Book 4, Utility Services. These descriptions include discussions of major assemblies, physical characteristics, block diagrams, and interfaces. DRL 13, Volume I, Book 2, is incorporated by reference into this report as a detailed description of the GN&C Subsystem major assemblies and will become the primary working document for further analysis.

Section 3

RELIABILITY AND MAINTAINABILITY ANALYSES

3.1 CRITICALITY ANALYSIS

As a guide to emphasis in subsequent checkout technique studies, an analysis has been made of the overall subsystem and major component criticality (failure probability) of the Space Station subsystems and equipment. As an input to the Checkout Requirements Analysis Task, this data along with the failure mode and effects data will be useful in determining test priorities and test scheduling. Additionally, this data will aid in optimizing checkout system design to ensure that confidence of failure detection is increased in proportion to added system complexity and cost.

3.1.1 CRITICALITY ANALYSIS PROCEDURE

A criticality number (related to failure probability) was generated for each major subsystem component. This number is the product of: (1) the component failure rate (or the reciprocal of mean-time-between-failure), (2) the component's anticipated usage or duty cycle, and (3) an orbital time period of six months, or 4,380 hours. Six months was chosen as the time period of interest to allow one missed resupply on the basis of normal resupply occurring at three-month intervals. The criticality number, then, is the failure expectation for a particular component over any six-month time period.

For visibility, the major components of each subsystem analyzed have been ordered according to the magnitude of their criticality numbers. This number, however, should not be considered as an indication of the real risk involved, since it does not take into account such factors as redundant components, subsystem maintainability, and the alternate operational procedures available.

Overall subsystem criticality has been determined by a computerized optimization process whereby spares and redundancy are considered in terms of a trade-off between increased reliability and weight. This determination, therefore, reflects not only the failure probability of subsystem components, but also the probability that a spare or redundant component may not be available to restore the subsystem to operational status. The methodology used is described in Section 9, Long-Life Assurance Study Results, DRL 13 (Preliminary Subsystem Design Data), Volume III (Supporting Analyses), Book 4 (Safety/Long Life/Test Philosophy) from the MDAC Phase B Space Station Study. Component-level failure mode and criticality data are presented in subsequent paragraphs.

3.1.2 SUBSYSTEM CRITICALITY DATA

The Guidance, Navigation and Control (GN&C) Subsystem has a six-month reliability of 0.998 and requires 1,000 pounds of spares for its achievement. An ordered ranking of GN&C component criticality is provided in Table 3-1.

3.2 FAILURE EFFECTS ANALYSIS (FEA)

The procedure employed in this section is similar to that of the earlier FEA analysis, except that a distinction was made between "single" and "multiple" failures. The term "multiple failures" implies complete loss of the function under consideration. A description of the baseline subsystems is contained in Section 2.

Generally, this FEA, coupled with other results, indicates that no failure modes exist which invalidate the onboard checkout concepts. It is noted that this analysis was conducted at the component level, commensurate with available Space Station subsystem design definition.

The results of the Guidance, Navigation and Control (GN&C) Subsystem FEA are given partially in Table 3-2, as an example.

3.3 MAINTENANCE CONCEPTS

General maintenance concepts are discussed in Section 7. Those specifically applicable to the GN&C Subsystem are discussed below.

The Guidance, Navigation and Control (GN&C) assemblies will be designed for maintenance at the modular level except for the precision sensor assemblies. The sensor assemblies, in general, will be replaced as a unit because of the tight mechanical tolerances involved in the assembly packaging. The instrument gyros shall be replaceable individually from the gyro assembly; and all gyros shall be interchangeable. Onboard calibration of the gyros shall be used to define their sensitive axis alignment.

The various control and interface electronics shall be contained in standardized plug-in modules.

The control moment gyros shall be located in pressurized (or pressurizable) compartments for ready access to maintenance. CMGs shall be designed for component repair/replacement capability.

Table 3-1. Guidance, Navigation, and Control Criticality Ranking

Component	Single Unit Criticality (10 ⁻⁶)	Conditioned Loss Criticality (10 ⁻⁶)	Remarks
Attitude Gyro Assembly	87,600	760	Considers backup for each of 3 gyros
Sensor Interface Electronics	72,000	500	Estimate based on internal redundancy and backup unit
Star Sensor Assembly	50,000	300	Considers horizon sensor assembly as degraded backup means of S/S reference
CMG Electronics	44,000	50	Includes risk that nonoperating electronics has failed
Star Tracker Assembly	41,800	72	Considers one operating and one nonoperating backup
Control Moment Gyro	21,900	<100	Two nonoperating CMGs
Landmark Tracker Assembly	8,800	8	Includes risk that nonoperating backup is failed
Alignment Monitoring System	8,800	<10	Considers backup spares failure risk
Low-g Accelerometer	8,780	8	Considers failure of nonoperating backup
Horizon Detector	7,200	50	Either detector can provide course attitude info during artificial-g

Trackers and sensors mounted externally shall be designed for retraction to permit repair and replacement in a pressurized volume (shirtsleeve). To provide access to the sensor for maintenance, the sensor mount is remotely hinged into the unpressurized sensor bay. A hatch is positioned over the opening, sealed, and the sensor bay is pressurized. Then, an access hatch is opened from the common module to allow sensor maintenance. Sensor alignment and calibration are provided by the calibration base, which is a structurally rigid element with alignment monitoring reflectors on the inside end and calibration targets on the outside end. After replacement and positioning of the sensor in its operational configuration, the alignment monitor determines the calibration base alignment. The sensor is then pointed to acquire the targets on the calibration base while the corresponding sensor outputs are read off for calibration.

The laser docking trackers shall incorporate indicators at the docking safety officer station to indicate substandard performance with regard to critical parameters subject to maintenance control.

3.4 LINE REPLACEABLE UNIT ANALYSIS

General guidelines and criteria for the definition of LRUs were established and these, with the maintenance philosophies, were used to determine at what level line maintenance would be performed. For the Space Station Subsystems specific justification applicable to LRU selection for the particular subsystem under examination was derived from the guidelines and these justifications are presented along with the LRU listing. The "functional LRUs" were then considered in the light of the standard electronic packaging scheme and actual LRUs were defined and listed. The method employed and the results achieved are discussed in the following sections.

3.4.1 SPACE STATION SUBSYSTEM LRUs

The definition of Line Replaceable Units (LRUs) is keyed to repairing subsystems in an in-place configuration with the LRU being the smallest modular unit suitable for replacement. General factors considered in identifying subsystem LRUs include: (1) Space Station maintenance concepts; (2) the component-level failure rates delineated in the criticality analyses; (3) the amount of crew time and skill required for fault isolation and repair; (4) resultant DMS hardware and software complexity; and (5) subsystem weight, volume, location, and interchangeability characteristics. Listings of LRUs and more specific justification for their selection follows.

Guidance, Navigation and Control (GN&C) Subsystem LRUs are listed in Table 3-2. Their selection is influenced largely by the specialized functional characteristics of GN&C components and the state-of-the-art in their packaging.

Table 3-2. Guidance, Navigation, and Control LRUs

LRU	Quantity	
	Required	Standby Redundant
Horizon Detector	2	
Gyro Assembly		
Gyros	6	
Gyro Electronics Assembly	6	
Gyro and Accelerometer Mount Assembly	2	
Gyro Power Supply	2	
Horizon Sensor Assembly		
Horizon Sensors	4	
Horizon Sensor Mount Assembly	1	
Star Sensor Assembly		
Star Sensors	2	
Star Sensor Mount Assembly	2	
Star Tracker Assembly		
Star Trackers	2	1
Tracker Electronics Assembly	2	1
Tracker Mount Assembly	2	1
Landmark Tracker Assembly		
Landmark Tracker	1	1
Tracker Electronics Assembly	1	1
Tracker Mount Assembly	1	1
Accelerometer Assembly		
Accelerometer	1	1
Accelerometer Electronics	1	1
Rendezvous Tracker Assembly		
Tracker Assembly	4	
Gimbal Mount Assembly	4	
Electronics Assembly	4	
Docking Tracker Assembly		
Tracker Assembly	7	
Tracker Electronics Assembly	7	

Table 3-2. Guidance, Navigation, and Control LRUs (Continued)

LRU	Quantity	
	Required	Standby Redundant
Alignment Monitor Assembly (Sensors)		
Signal Transceiver	2	
Signal Receiver	2	
Alignment Monitor Assembly (Experiments)		
Signal Receiver	2	
Signal Source	2	
Interface Electronics Assembly		
Inertial Sensor Buffer Module	2	2
Horizon Sensor Buffer Module	1	1
Stellar Sensor Buffer Module	1	1
Landmark and Alignment Sensor Buffer Module	1	1
Laser Tracker Buffer Module	2	2
CMG Control Buffer Module	4	4
Reaction Jet Control Buffer Module	2	2
Data Control Module	4	4
Jet Driver Electronics Assembly		
High Thrust Jet Driver Module	4	
Resistojet Control Module	4	
Backup Control Electronics Module		2
CMG Assembly		
CMG Rotor Gimbal Assembly	4	2
Torquer Assembly (Inner Gimbal)	4	2
Torquer Assembly (Outer Gimbal)	4	2
CMG Electronics Assembly		
CMG Rotor Control Modules	4	2
CMG Torquer Control Modules	4	2

Sensing devices used in the GN&C Subsystem are mainly electromechanical or electro-optical in nature, and are generally configured with a sensor and a separate electronics package. In addition, most precision sensing devices are mounted on or within a specially designed structure for tight alignment tolerances and environment control. Gimbal-mounted tracking sensors, for example, are replaced as a unit with the gimbals since the tight mechanical tolerances for the gimbals are expected to be only maintainable on the ground.

Electronic assemblies which interface with the sensors, actuators, and data acquisition equipment of the Data Management Subsystem consist of groups of similar or identical circuits. These are modularized and replaced at the module level to take advantage of having a common spare configuration for several functions.

Control Moment Gyro Assemblies (CMGs) are large electromechanical devices which are constructed for long life operation with tight mechanical tolerances. The only on-orbit repair capability planned for these assemblies is the replacement of torquer-resolver units. The mechanical tolerance level required for long CMG life requires further breakthroughs in design technology before bearings and rotor can be considered as being replaceable on orbit.

Section 4

OCS CHECKOUT STRATEGIES

4.1 SUBSYSTEM CHECKOUT STRATEGY

Before further requirements analysis, it is necessary to develop a checkout strategy for all Space Station subsystems to meet checkout objectives, which can be summarized as follows:

- To increase crew and equipment safety by providing an immediate indication of out-of-tolerance conditions
- To improve system availability and long-life subsystems assuarcy by expediting maintenance tasks and increasing the probability that systems will function when needed
- To provide flexibility to accommodate changes and growth in both hardware and software
- To minimize development and operational risks

Specific mission or vehicle-related objectives which can be imposed upon subsystem level equipment and subsystem responsibilities include the following:

- OCS should be largely autonomous of ground control.
- Crew participation in routine checkout functions should be minimized.
- The design should be modular in both hardware and software to accommodate growth and changes .
- OCS should be integrated with, or have design commonality with, other onboard hardware or software .
- The OCS should use a standard hardware interface with equipment under test to facilitate the transfer of data and to make the system responsive to changes.
- Failures should be isolated to an LRU such that the faulty unit can be quickly removed and replaced with an operational unit.

- A Caution and Warning System should be provided to facilitate crew warning and automatic "safing" where required.
- Provisions must be included to select and transmit any part or all of the OCS test data points to the ground.

To attain these objectives via the use of an Onboard Checkout System which is integrated with the Data Management System, checkout strategies have been developed which are tailored to each Space Station subsystem.

Special emphasis has been applied to a strategy for checkout of redundant elements peculiar to each subsystem. The degree to which each of these functions is integrated into the DMS is also addressed.

4.1.1 SPACE STATION SUBSYSTEMS

Each major Space Station subsystem was examined with respect to the required checkout functions. The checkout functions associated with each subsystem are identified and analyzed as to their impact on the onboard checkout task. The functions considered are those necessary to verify operational status, detect and isolate faults, and to verify proper operation following fault correction. Specific functional requirements considered include stimulus generation, sensing, signal conditioning, limit checking, trend analysis, and fault isolation.

4.1.1.1 Guidance, Navigation, and Control Subsystem

The Guidance, Navigation, and Control (GN&C) Subsystem contains the sensors, including gyroscopes, accelerometers, horizon sensors, star trackers, and landmark trackers, and the associated electronics required to provide attitude stabilization and navigation for the Space Station. The subsystem also includes laser devices for rendezvous and docking.

4.1.1.1.1 Checkout Functions

Checkout and fault isolation of the GN&C Subsystem involves a combination of operational limit and validity checks and functional testing. Normal operational monitoring utilizes the inherent self-verification capability of the subsystems which accrues from redundant and complementary attitude and navigational sensing features. Items such as gyros, accelerometers, horizon sensors, star sensors, star trackers, and landmark trackers are implemented redundantly, allowing cross-correlation of outputs from the multiple units. Further, certain of these sensors are complementary to each other, allowing an additional dimension of correlation. Star tracker outputs, for example, can be checked against landmark tracking data for validation. Fault isolation is accomplished by majority voting

techniques and by input/output functional testing using combinations of normal operational functions and artificial test stimuli. Examples of the latter include a simulated star source which is part of the star tracker assembly, torquing coils for stimulation of gyro outputs, and sensor output simulation signals for verification of downstream electronics. Other forms of operational monitoring include limit testing and trend analysis of selected performance parameters.

- Stimulus Generation - Checkout stimuli are required to perform periodic subsystem functional tests and calibrations and to aid in fault isolation to the LRU level. Typical stimuli include gyro torquing signals, simulated detector outputs for the horizon sensors, star sensors, star trackers, landmark trackers, accelerometers, and various test stimuli for the associated electronics packages such as the jet driver logic. These are in addition to the normal control signals such as switching and gimbal commands.
- Sensing - A detailed listing of measurement requirements is included in the Task 1 final report.
- Signal Conditioning - Measurement signal conditioning is required to normalize the sensor outputs listed above. The required conditioning circuitry is provided as an integral part of the sensor assembly or in the Interface Buffers which provide the interface between the attitude and navigational sensors and the preprocessors.
- Limit Checking and Trend Analysis - Continuous or periodic limit checking is required on a small number of parameters such as gyro temperature and CMG rotational speed, vibration, and bearing temperature. Trend analysis of the CMG functions is expected to be meaningful in predicting wearout or failure of these units.

4.1.1.1.2 Redundant Element Checkout

Redundancy in the GN&C Subsystem is predominantly in the form of installed and operational equipment such as redundant accelerometers, horizon sensors, star trackers, etc. The redundant equipment is normally on line and is implemented in such a way that it can be tested independently without disturbing system operation. It therefore presents no special problems from the checkout standpoint. An exception is the spare CMGs, which are installed in a standby (nonoperating) condition. The standby units must be tested periodically to assure availability. This periodic test will consist of a partial spin-up and gimbal check. Full speed spin-ups are not planned because of the long time (several hours) required to achieve rated speed and because full speed is not necessary to verify operation.

4.1.1.1.3 Integration with Data Management Subsystem

All control functions as well as the test sequencing and fault isolation for the GN&C Subsystem are performed by the DMS computer. Test stimuli generators and measurement signal conditioning are contained in the GN&C Subsystem. The subsystem interfaces with the DMS through the GN&C interface buffers. These buffers receive control information from the DMS in digital form and provide the necessary logic, signal routing, digital-to-analog conversion, and other functions required to control the GN&C equipment. The buffers also provide the multiplexing and analog-to-digital conversion required to translate the GN&C equipment outputs to digital formats compatible with the DMS interface.

4.2 INTEGRATED CHECKOUT STRATEGY

This analysis identifies the integrated checkout functions associated with Space Station subsystems during the manned orbital phase of the mission. These functions are depicted in Figure 4-1 and are those required to ensure overall availability of the Space Station. Characteristic of integrated testing is the fact that the test involves subsystem interfaces, and, therefore, test objectives are associated with more than one subsystem.

4.2.1 INTEGRATED STRATEGY

Six checkout functions have been identified:

- Caution and warning
- Fault detection
- Trend analysis
- Operational status
- Periodic checkout
- Fault isolation

These functions represent a checkout strategy of continuous monitoring and periodic testing with eventual fault isolation to a line replaceable unit (LRU). Under this aspect the functions are grouped as -

<u>CONTINUOUS MONITORING</u>	<u>PERIODIC TESTING</u>	<u>FAULT ISOLATION</u>
<ul style="list-style-type: none">● Caution and warning● Fault detection● Trend analysis● Operational status	<ul style="list-style-type: none">● Automatic tests● Operational Verification	<ul style="list-style-type: none">● Localize to SS● Isolate to RLU

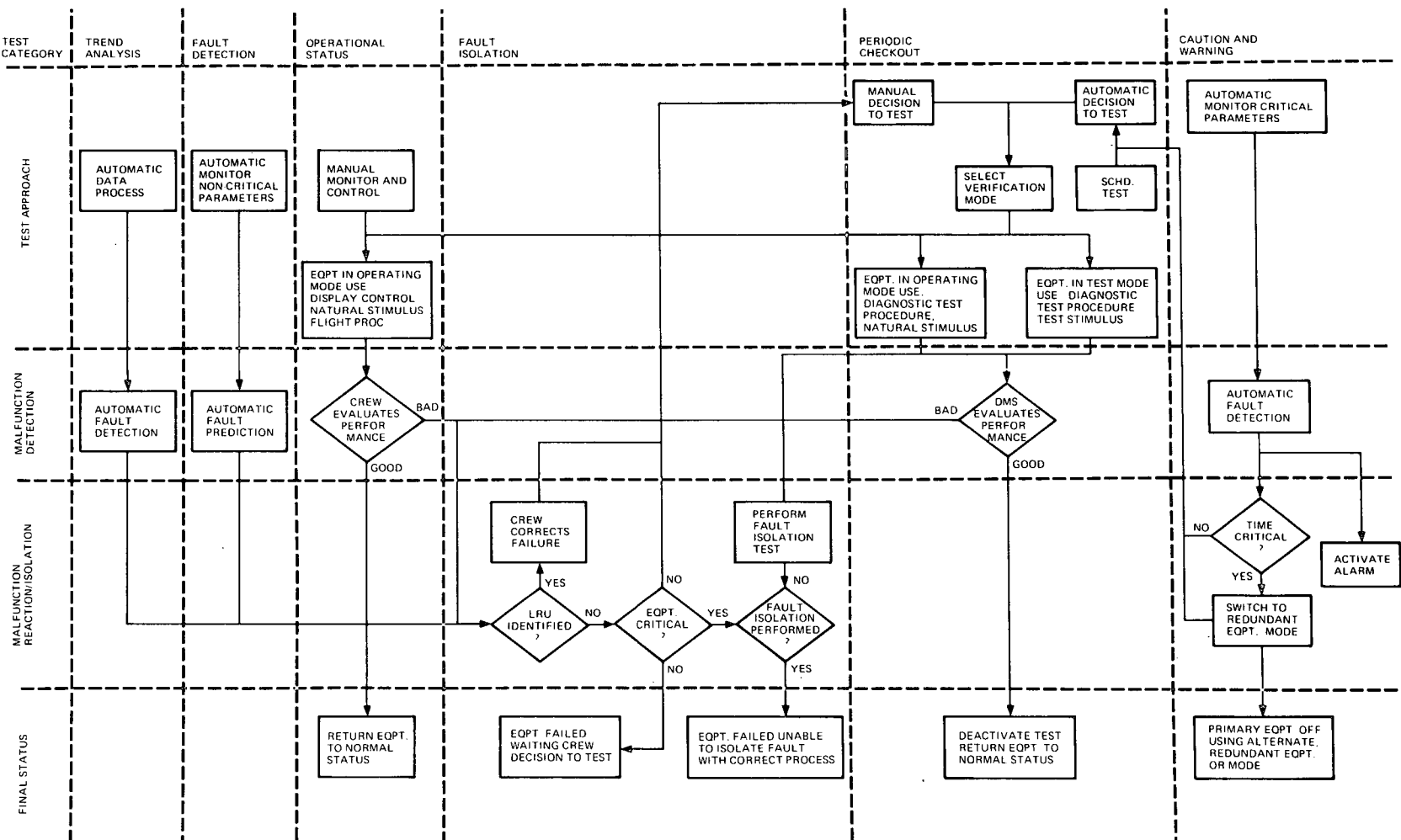


Figure 4-1. Integrated Checkout Functional Flow

General characteristics of these groups are defined below:

4.2.1.1 Continuous Monitoring

Continuous monitoring is not a test per se. It is a concept of continuously sampling and evaluating key subsystem parameters for in/out-of-tolerance conditions. This evaluation does not necessarily confirm that the subsystems have failed or are operating properly. The evaluation is only indicative of the general status of the subsystems. For example, a condition exists where the integrated subsystems are indicating in-limit conditions, but during the next series of attitude control commands, an error in Space Station position is sensed and displayed. Since three subsystems, DMS, GN&C, and P/RCS, are involved in generating and controlling the Space Station attitude, a "positional error" malfunction is not directly related to a subsystem malfunction. The malfunction indication is only indicative of an out-of-tolerance condition of an integrated function. Final resolution of the problem to a subsystem and eventually to LRU will require diagnostic test-procedures that are separate from the continuous monitoring function.

There are situations in which the parameters being monitored are intended to be directly indicative of the condition of a subsystem or an LRU. Examples of these include tank pressures, bearing temperatures, and power source voltages. However, even in these simpler cases when a malfunction is detected, an integrated evaluation will be performed to ascertain that external control functions, transducers, signal conditioning, and the DMS functions of data acquisition, transmission, and computation are performing properly. This evaluation will result in either a substantiation of the malfunction or identification of a problem external to the parameter being monitored.

Figure 4-1 shows the logic associated with each function in the continuous monitoring group, as well as the integrated relationships between these and the total checkout functions. The caution/warning and fault detection functions are alike in their automatic test and malfunction detection approaches, but are different in terms of parameter criticality and malfunction reaction. The caution/warning function monitors parameters that are indicative of conditions critical to crew or equipment safety. Parameters not meeting this criticality criteria are handled as fault detection functions. Figure 4-1 shows that in the event of a critical malfunction, automatic action is initiated to warn the crew and sequence the subsystems to a safe condition. Before this automatic action is taken, the subsystems must be evaluated to ascertain that the failure indication is not a false alarm and that the corrective action can be implemented. After the action is taken, the subsystems must be evaluated to determine that proper crew safety conditions exist. Since automatic failure detection and switching can be integral to subsystem design (self-contained correction) and subsystems can be controlled by the operational software or manual controls, it is imperative that the status of these events be maintained and that the fault detection and correction software be interfaced with the prime controlling software. For malfunctions that are not critical, the crew is notified of their occurrence, but any subsequent action is initiated manually.

The next continuous monitoring function, trend analysis, automatically acquires data and analyzes the historical pattern to determine signal drift and the need for unscheduled calibration. It also predicts faults and indicates the need for diagnostic and fault isolation activities. An example of a parameter in this category is the partial pressure of nitrogen. Nitrogen is used to establish the proper total pressure of the Space Station. Since it is an inert gas, the only make-up requirements are those demanded by leakage or airlock operation. The actual nitrogen flow rate is measured, and calculations are performed which make allowances for normal leakage and operational use. When these calculations indicate a trend toward more than anticipated use, the crew is automatically notified and testing is initiated to isolate the problem to the gas storage and control equipment or to an excessive leak path. The historical data is not only useful in predicting conditions but is also useful in providing trouble-shooting clues. The data might reveal, for example, that the makeup rate increased significantly after the use of an airlock. This could lead directly to verifying excessive seal leakage.

The final continuous monitor function is in operational status. This function is performed by the crew and is nonautomatic with the exception of the DMS computer programs associated with normal Space Station operational control and display functions. The concept of continuous monitoring recognized and takes advantage of the crew's presence and judgment in evaluating Space Station performance. In many instances the crew can discern between acceptable and unacceptable performance, and they can clearly recognize physically-damaged equipment or abnormal conditions.

4.2.1.2 Periodic Testing

As opposed to continuous monitoring, periodic testing is a detailed evaluation of how well the Space Station subsystems are performing. Figure 4-1 shows that periodic testing is not accomplished by any one technique. Rather, a combination of operational and automatic test approaches is employed. The actual operational use of equipment is often the best check of the performance of that equipment. Operation of Space Station equipment and use of the normal operating controls and displays will be used in detecting faults and degradation in the subsystems. This mode of testing is primarily limited to that equipment whose performance characteristics are easily discernible, such as for motors, lighting circuits, and alarm functions.

Automatic testing is performed in two basic modes:

- With the subsystems in an operating mode, the DMS executes a diagnostic test procedure which verifies that integrated Space Station functions

are being properly performed under normal interface conditions in response to natural or designed stimulation. This mode of testing allows the evaluation of Space Station performance without interrupting mission operations.

- For those situations where the integrated performance or interface compatibility between subsystems cannot be determined without known references or control conditions, the DMS will execute a diagnostic procedure in a test mode. In this mode, control, reference, or bias signals will be switched in or superimposed on the subsystems to allow an exact determination of their performance or localization of problem between the interfaces. Since the test mode may temporarily inhibit normal operations, the DMS must interleave the test and operational software to maintain the Space Station in a known and safe configuration.

The scheduled automatic tests are performed to verify availability or proper configuration of "on-line" subsystems, redundant equipment, and alternate modes.

- Periodic Verification of "On-Line" Subsystems - The first checkout requirement is a periodic verification that on-line subsystems are operating within acceptable performance margins. The acceptable criteria for this evaluation is based on subsystem parameter limits and characteristics exhibited during Space Station factory acceptance or pre-flight testing. The rejection criteria and subsequent decision to repair or reconfigure subsystems is based on the criticality of the failure mode. If the subsystems appear to be operating properly, but the test clearly indicates an out-of-tolerance condition, then one of the following alternatives must be implemented:
 - If the failure mode is critical, the crew normally takes immediate action to isolate and clear the problem.
 - If the failure mode is not critical, the crew can take immediate action, schedule the work at a later time, or wait until the condition degrades to an unacceptable level.
- Redundant Equipment Verification - A second checkout requirement is verifying that standby, off-line, or redundant equipment and associated control and switching mechanisms are operable. The acceptable/rejection criteria for these evaluations is identical to those for normally operating equipment. A primary distinction of this function is that equipment may have known failures from previous usage or tests. This situation occurs when the crew has knowledge of a failure but has not elected to perform the necessary corrective action. The checkout

function then becomes one of equipment status accounting and maintenance/repair scheduling. The status information is interlocked with mission procedures and software to preclude activation of failed units while they are being repaired or until proper operation following repair is verified.

- Alternate Mode Verification - The third checkout function is verifying the availability of alternate modes of operation. This function is essentially a confidence check of the compatibility of subsystems' interaction and performance during and after a change in the operating mode. To some extent this function overlaps with redundant equipment verification, but is broader in scope in that it verifies other system-operating characteristics. For example, some modes will involve manual override or control of automatic functions or automatic power-down sequences.

4.2.1.3 Fault Isolation

Fault isolation to an LRU is a Space Station goal. As shown in Figure 4-1, fault isolation testing is initiated when malfunction indications cannot be directly related to a failed LRU. The integrated test functions associated with fault isolation are localizing a malfunction to a subsystem or to an explicit interface between two subsystems and identifying the subroutine test necessary for LRU isolation. In structuring this relationship between integrated subsystem tests for fault localization and subroutine tests for fault isolation, the DMS, in conjunction with the test procedure documentation, must establish an effective man-machine interface so that in the event of an unsolved malfunction the crew will be able to help evaluate the condition and determine other test sequences necessary to isolate the problem. To accomplish this requirement, the DMS must be capable of displaying test parameters and instructions in engineering units and language and be capable of referencing these outputs to applicable documentation or programs that correlate test results to corrective action required by the crew.

Section 5

ONBOARD CHECKOUT TEST DEFINITIONS

5.1 SUBSYSTEM TEST DEFINITIONS

The on-orbit tests required to insure the availability of the Space Station subsystems are defined herein. Also delineated are the measurement and stimulus parameters required to perform these tests. Two discrete levels of testing are defined, i.e., continuous status monitoring tests for fault detection of critical and noncritical parameters, and subsystem fault isolation tests for localization of faults to a specific Line Replaceable Unit. In addition to these two levels, tests are defined for periodic checkout and calibration of certain units, and parameters requiring analysis of trends are defined.

Due to the software module approach to DMS checkout, it was deemed necessary to estimate the CPU time and memory required to implement these modules along with an assessment of the services required from an Executive Software System to control the checkout.

These test descriptions, measurement, and stimulus information provided for each subsystem, and the software sizing information provided for the Data Management System provide the data required to estimate the checkout impact on the DMS software and hardware. Table 5-1 is a summary of the measurement and stimulus requirements for the Space Station.

The Guidance, Navigation and Control (GN&C) Subsystem operates in a closed-loop mode with the Data Management and Propulsion Subsystems as elements of the loop. Normal operation is fully autonomous. Station attitude, position, and rate information are derived by the DMS from the GN&C sensors such as star trackers, horizon sensors, gyros, and accelerometers. Reaction controls are then computed by the DMS and transmitted to the propulsion thrusters. GN&C operation is thus closely integrated with both of these other subsystems. Operation is also influenced to a high degree by external factors such as shifts in vehicle mass, drag, and center of gravity and by disturbances such as docking impacts. These factors must be accounted for in performing checkout and fault isolation tasks.

Table 5-1. Measurement/Stimulus Summary

SUBSYSTEM	STIMULUS					RESPONSE			STATUS MONITORING								Fault Isolation	Remarks
	Analog	Bilevel	Digital	Pulse	RF	Analog	Bilevel	Digital	Total	Non-Critical	Caution	Warning	Periodic Checkout	Calibration	Trend			
Guidance, Navigation and Control	20	145	62	6		127	161	70	692	130	16		516	74	74	592		
Propulsion-Low Thrust		134				120	124		378	152	14		378	48	8	378		
Propulsion-High Thrust		126/62				287/117	123/63		536/242	80/28	33/15	14/10	536/242	259/111	117/43	482/222	Arc-g/Zero-a periods	
Environmental Control/ Life Support	12	111				683	294		1100	147	209	32	1100		135	1100	172 Caution/Warning Signals are for IVA/EVA	
RF Communications	37	206	36		77	131	286	28	801	58			576	24	93	801		
Structures	13/11	115/13				49/42	69/50		196/126	7			103/84			146/126		
Electrical Power-ICD	71	367				523	454		1415	520	18		993		143	1415		
Electrical Power-I/BR	6	2				132	48		188	2	28	8	32		17	176		
Data Management			53			33	188	83	357	357			62	62	62	357		
		1107/				2085/	1747/		5511/	1755/			4296/			5415/		
Total	157/155	1041	151	6	77	1908	1678	181	5299	1401	318/300	54/50	3983	467/319	549/575	5165		

5.1.1 STATUS MONITORING

Fault detection within the GN&C Subsystem is accomplished primarily by monitoring of selected performance parameters and comparing the resulting measured or computed values with predetermined limits and/or against parallel redundant parameters. The parameters to be monitored in this manner are listed in the Status Monitoring column of Appendix I-1, Task 1 Final Report. Precise sampling intervals are not required. Detection of an out-of-limit condition results in immediate notification of the crew. In the case of critical parameters or where otherwise deemed desirable, an automatic fault isolation routine is automatically initiated to identify the faulty LRU. Otherwise, initiation of further action is a crew option.

Fault detection procedures must be conditioned where necessary to account for external disturbances. For example, leakage or venting from the Station will cause a response to the subsystem similar to that of a failed open reaction jet. A change in the Station configuration, such as that due to docking or undocking of experiment or crew cargo modules will result in subsystem performance perturbations which can be interpreted as faults unless these events are accounted for in the subsystem logic.

Sixteen caution functions have been identified for the GN&C Subsystem. These are the bearing temperature and vibration monitors for the CMGs.

5.1.2 TREND ANALYSIS

Certain of the GN&C performance parameters are amenable to trend analysis for detection of degradation or pending failure. These are identified in the Trend column of Appendix I-1, Task 1 Final Report. Included are gyro and accelerometer temperatures, laser transmitter power and CMG spin rate, temperature, and vibration. Trend data of another type is required on the frequency and duration of high thrust reaction jet firing. This data is necessary to determine actual versus scheduled energy requirements and fuel consumption.

5.1.3 PERIODIC CHECKOUT AND CALIBRATION

Since most GN&C faults are detectable by operational monitoring, periodic checks are performed primarily to ascertain that qualitative performance parameter degradations which are not obviously detectable have not occurred, and to detect failures in inactive or standby equipment. Calibration is a subtask of the periodic checkout and will be conducted during the periodic event. Checkout intervals are nominally once per month based on predicted performances of the components. The horizon detectors for artificial-g operation, star trackers for inertial orientation, and rendezvous and docking trackers are used infrequently and will require function testing prior to the respective events. The automatic

landmark tracker, which is a new flight item, is checked once per week for the first year when it is being flight tested. After the first year, it is checked once per month, as is the rest of the subsystem.

Checkout utilizes preprogrammed checkout routines and employs the technique of introducing calibrated stimuli at the first practical point in the forward path of the GN&C loop and monitoring subsequent downstream points for checks and calibration. Most of the downstream monitoring points are operational data interfaces with the DMS and DMS-computed data, such as attitude or position errors. The test sequence therefore begins with verification, through self-diagnostic routines, of the DMS software and DMS/GN&C interfaces. This is followed by verification of the sensor electronics and data buffers and of the sensors themselves. The final portion of the sequence checks the reaction control elements of the subsystem, including the CMGs and the jet drivers.

5.1.4 FAULT ISOLATION

All stimulus and measurement parameters are utilized for fault isolation. As indicated previously, fault detection is accomplished through direct measurement of these parameters or through DMS computations based upon these measurements. The DMS-computed fault detection is generally at the system level and is in terms of excessive attitude, position, or instrument pointing errors. The directly detected faults, such as excessive CMG bearing temperature, are generally more component or assembly oriented. In either case, the fault isolation function involves systematic analysis of the fault indicators and associated functions using the normal operating input/output relationships plus special test stimuli where necessary. Applicable portions of the periodic checkout routines are used.

Since fault isolation is to the LRU level, some of the more familiar component monitor parameters are omitted from the stimulus/measurement list. An example is the spin rate monitor of the instrument gyro. This is an often monitored function in many applications but in this instance, the gyro performance is verified by the response to a command torquing signal which checks the gyro as an overall transfer function. If the response is out-of-specification, then the gyro as an LRU will be replaced regardless of whether it was the spin rate, signal generator, torquer scale factor, or any other fault which cause the deviation.

A typical test and fault isolation routine is diagrammed in Figure 5-1. This routine involves the Laser Rendezvous Tracker, which is used to acquire and track docking targets. The device transmits a coherent parallel pulsed light beam and detects energy returned from a passive reflector on the target vehicle. Course pointing of the beam is achieved by mechanical gimbals, while fine pointing is achieved by a piezoelectric beam deflector and optical deflection amplifier. The

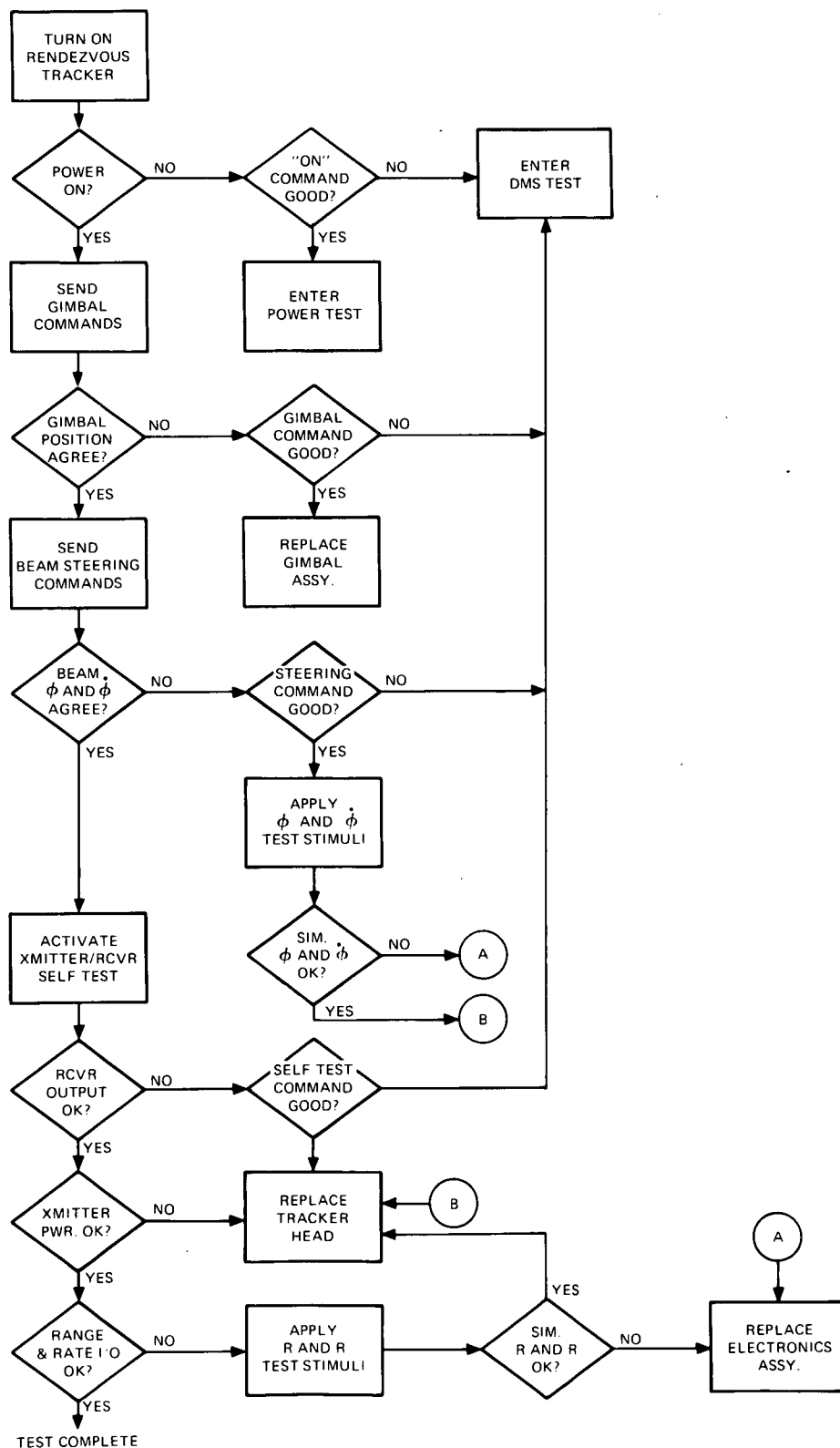


Figure 5-1. Rendezvous Tracker Test

device provides angles, range, and range rate as outputs. Three LRUs are involved, these being the tracker head, the gimbal assembly, and the electronics assembly. The tracker head includes an optical self-test mode which allows a portion of the transmitted pulse to be reflected back into the receiver.

The test sequence shown in Figure 5-1 assumes that no actual target is available. The test is therefore not 100 percent complete in that the actual beam pointing accuracy cannot be verified.

5.2 INTEGRATED TEST DEFINITION

The task of ensuring overall Space Station availability is primarily dependent upon the proper structuring of individual subsystem tests. The ability to test the subsystems independent of other subsystems is directly related to the number and types of interfaces. As shown in Figure 5-2, the DMS and Electrical Power Subsystems (EPS) interface with every other Space Station subsystem. In addition, the EC/LS Subsystem provides cooling to most of the electronic packages. This situation demands that in constructing the test for a subsystem these interfaces be taken into account so that erroneous or ambiguous test results will not be obtained. In other words, before detailed subsystem fault isolation tests are initiated, a higher level of testing should be performed to verify that all interfaces and Space Station conditions that influence the subsystem are proper. Properly designed, these higher-level tests will (1) indicate what Space Station conditions must be verified, maintained, or changed; (2) localize the malfunction to a single subsystem; and (3) identify the subroutine test necessary for fault isolation.

Since the DMS interfaces with all of the Space Station subsystems and is used as the OCS, it would appear that all of the tests would be integrated. However, this is not a proper interpretation. When the DMS is used to verify the performance of another subsystem, it must first establish itself as a test standard against which the subsystem parameters are compared. Subsequent to this verification, the test is dedicated to the evaluation of the subsystem. This test would be considered as an independent test since the objective of the test was to verify the subsystem and not the DMS. For a test to be considered as an integrated test it must meet one or more of the following conditions:

- Test objectives associated with more than one subsystem
- Test involves subsystem interfaces
- Test requires proper operation of other subsystems

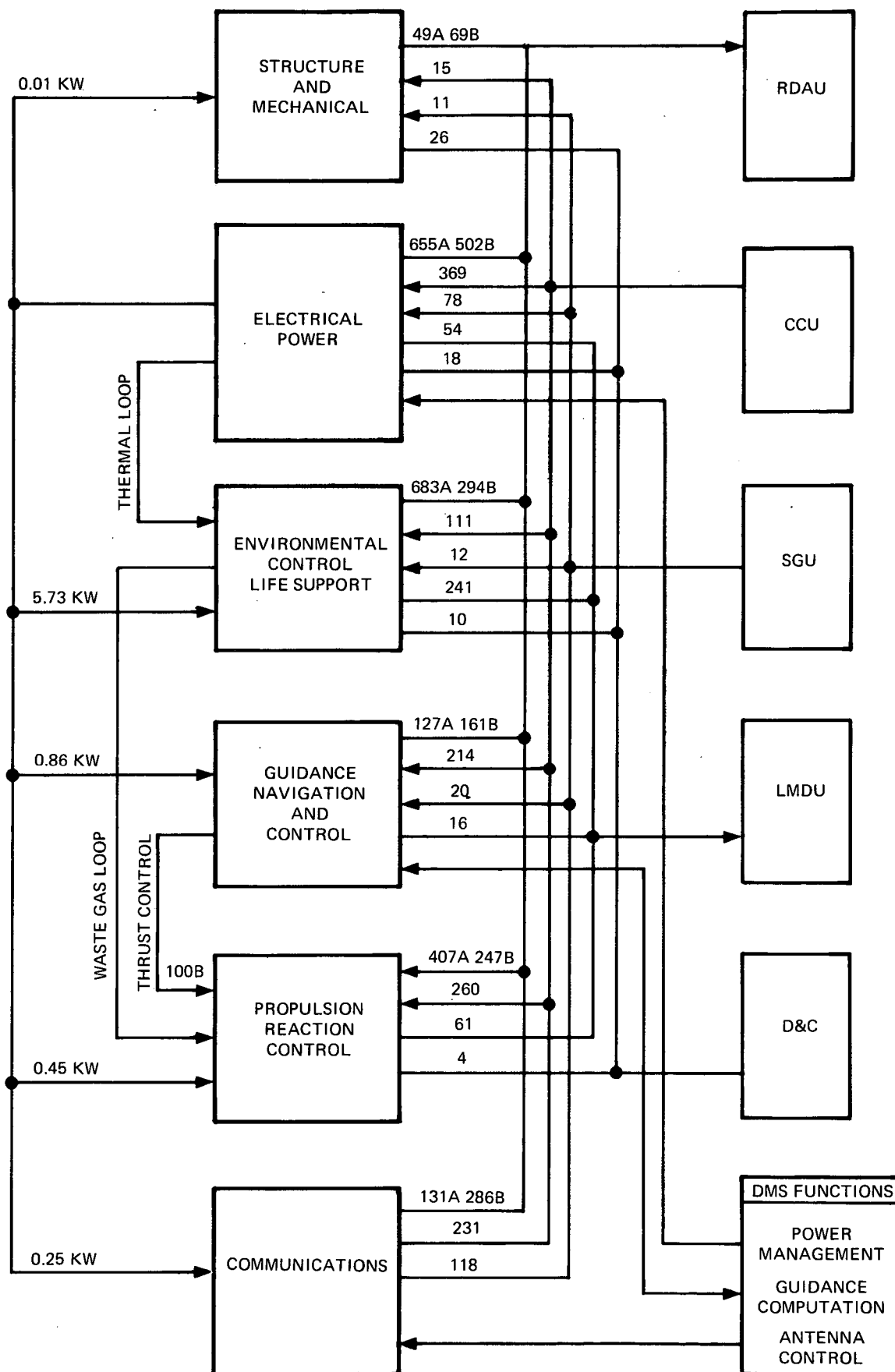


Figure 5-2. Subsystem Interfaces

In several cases, the DMS must simultaneously perform the dual role of OCS and functional elements. As an example, the DMS has a functional interface with the GN&C and Prop Subsystems for the computation of guidance equations and the execution of commands to the control actuators. When this functional closed loop is being tested, the DMS must, in addition to performing its normal functions, execute the test routine. For this type of integrated test there must be an intrinsic relationship between the operational and test software. This relationship must be carefully considered in structuring the integrated tests since unstable or intermittent performance may be detected only in the exact operating mode under closed-loop conditions. The number of integrated tests is not extensive due to the approach of minimizing the different types of interfaces between Space Station subsystems. For example, interfaces between the DMS and other subsystems are largely standardized. As a result, relatively common tests can be designed for verification of the multitude of DMS subsystem interfaces or for localization of a fault to one side of a DMS subsystem interface. All special integrated tests that have been identified are discussed in the following paragraphs. The GN&C/DMS/PROP configuration for navigation and attitude control poses the most difficult problem for on-orbit testing so it is presented in significant detail. Other integrated tests are summarized.

5.2.1 GN&C/DMS/PROP

5.2.1.1 Block Diagram

Figure 5-3 shows the block diagram for the GN&C/DMS/PROP Subsystems as configured for the zero g, horizontal mode of operation. The subsystems are shown at the LRU level with all primary functional interfaces. For simplicity, prime power inputs, cold plate interfaces, and mechanical or fluid connections are not shown.

5.2.1.2 Functional Description

The GN&C Subsystem accommodates both the artificial-g and zero-g operations of the Space Station. In the zero-g mode of operation, the GN&C Subsystem provides autonomous navigation, rendezvous command, traffic control, automatic docking, and stabilization and control of the Space Station.

The autonomous navigation scheme utilizes the stellar inertial reference data and the automatic landmark tracker augmented with the drag accelerometer. The navigation is accomplished by automatically tracking known and unknown landmarks several times each orbit. The landmark is similar in operation and mechanization to a gimballed star tracker. The drag accelerometer accounts for anomalies due to Space Station orientation and docked module changes which contribute to navigation errors.

Both ground tracking and onboard subsystems will provide the navigation information for the first year or so of the Space Station Program. The ground-generated data will be transmitted onboard for evaluation of the autonomous navigation system performance. As the confidence in autonomous operation is increased through this parallel operation, the ground tracking is to be phased out.

In all operating modes and orientations, the gyros provide the high-frequency rate and attitude information necessary to supplement the data from the stellar sensors and the horizon sensors.

A more accurate Earth-centered reference is obtained in the horizontal orientation through the use of the strapdown star sensors. The star sensors provide the long-term, drift-free inertial reference data while the gyros provide the short-term, high-frequency attitude and rate information. The passive star sensors are used while the Space Station is maintained in an Earth-centered orientation. The constant rotational rate required of the vehicle to maintain this type of orientation provides the scanning motion for the star sensors, which are completely passive and provide no tracking or scanning capability of their own.

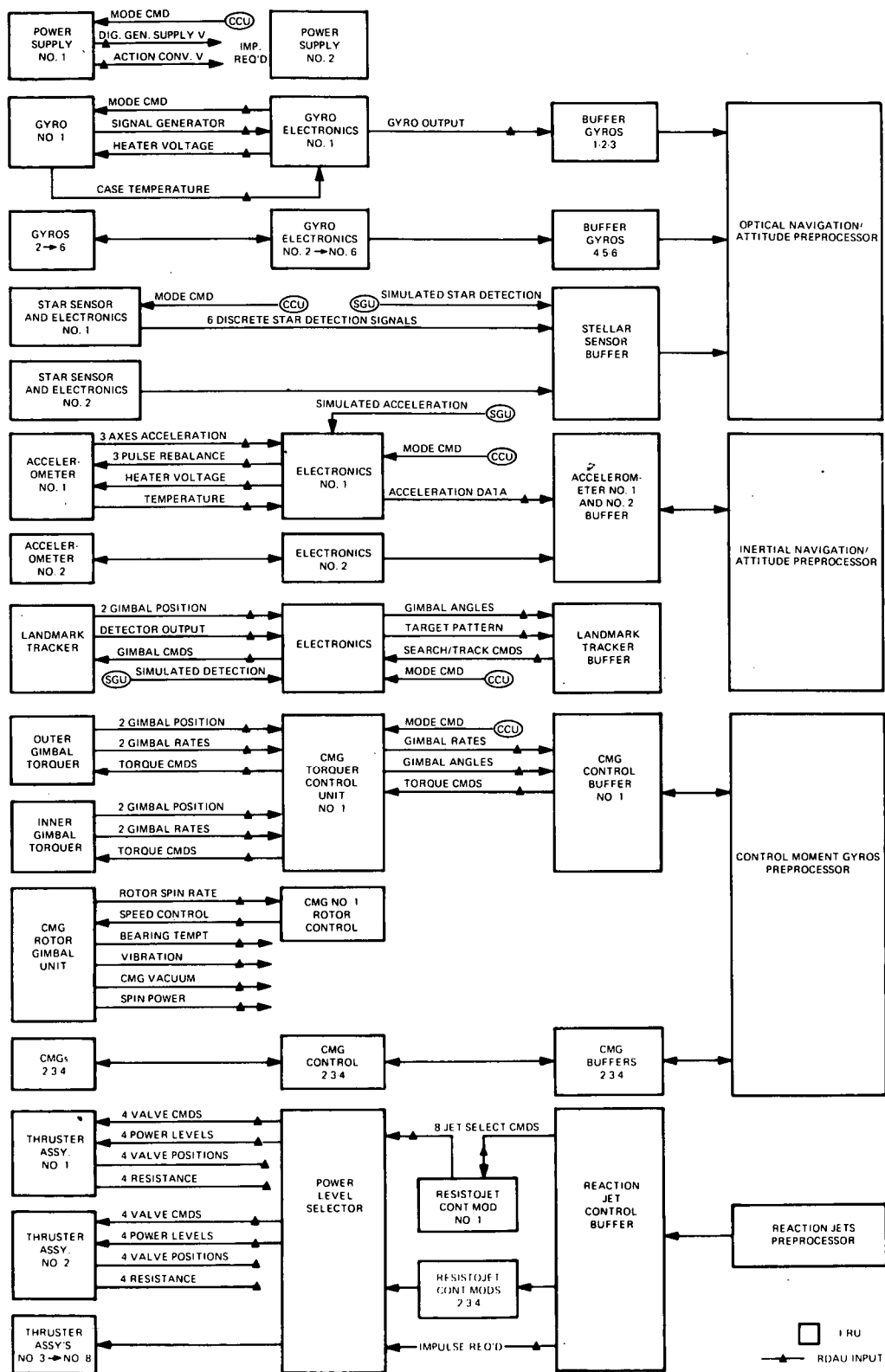


Figure 5-3.. GN&C/DMS/PROP Configuration for Zero-G Horizontal Mode

The sensors themselves provide inertial attitude data which is transformed into Earth-centered attitude information by use of the navigation parameters. By this method, both inertial attitude and Earth-centered attitude are derived from the passive star sensors while the vehicle is in the horizontal or other Earth-centered orientation. This Earth-centered orientation is considered to be most responsive to experiment and subsystem requirements.

Primary attitude control actuation is provided by control moment gyros (CMGs). A CMG configuration utilizing four double-gimballed CMGs, each having a momentum capacity of 1,100 ft-lb-sec, was selected for the isotope/Brayton-powered Space Station. Both High and Low-Thrust Propulsion Systems are utilized by the GN&C Subsystem for CMG desaturation and backup attitude control capability. The reaction jet control buffer provides the interface with the Propulsion Subsystem.

The DMS provides the link between the sensors, which are used to determine the vehicle angular position, and the actuators, which are used to maintain or change the vehicle angular position. The use of the DMS provides the flexibility required during both the development and operational phases to accommodate the total Space Station Program objectives. The DMS performs the data processing necessary for all guidance, navigation, and attitude control functions. The interface electronics controls the flow of information from the sensors to the DMS and converts all sensor inputs to a standardized format before the inputs are transferred. The interface electronics performs a similar function for output information from the DMS to the control actuators.

5.2.1.3 Test Flow

The test flow for the GN&C/DMS/PROP configuration is shown in Figure 5-4. The flow demonstrates the technique for malfunction detection, subsystem localization and fault isolation to the LRU. For simplicity some tests associated with prime power, mode commands and cold plate temperatures are omitted. It is assumed that in programming the actual tests these types of measurements will be implemented as standard procedure. In the same vein, detailed tests of the DMS are not shown. Again, it is assumed that the final procedure would contain the necessary self-test, command verification, and other checks to maintain confidence in DMS performance throughout the test.

Many of these test sequences will be repeated for different channels of data or for identical sets of equipment. The test flow does not show the repetition of these tests but indicates the need for them. For example, there are four control moment gyros (CMGs). The flow shows a typical test for one CMG. It should be

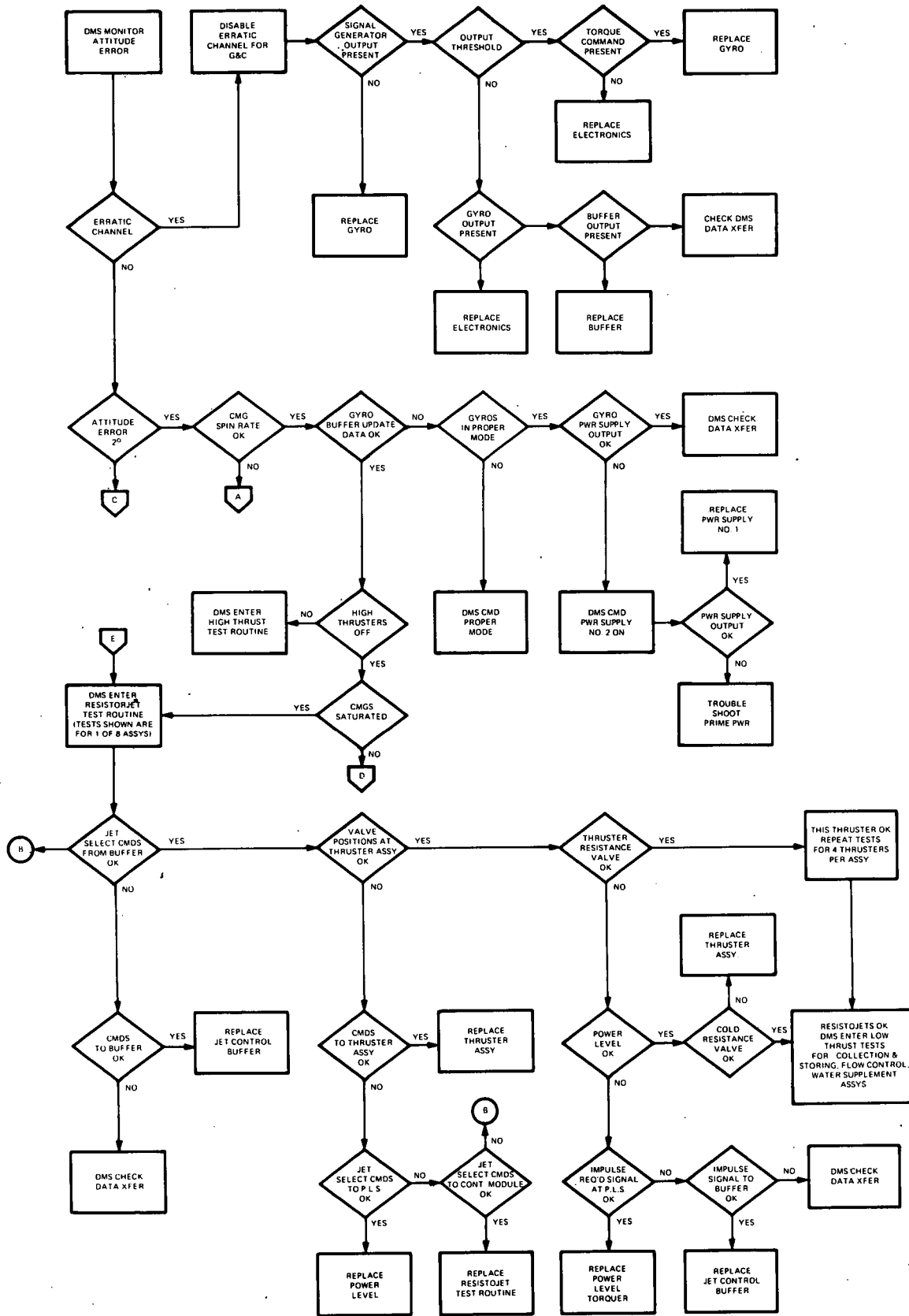


Figure 5-4.. GN&C/DMS/PROP Integrated Test Flow (Sheet 1 of 4)

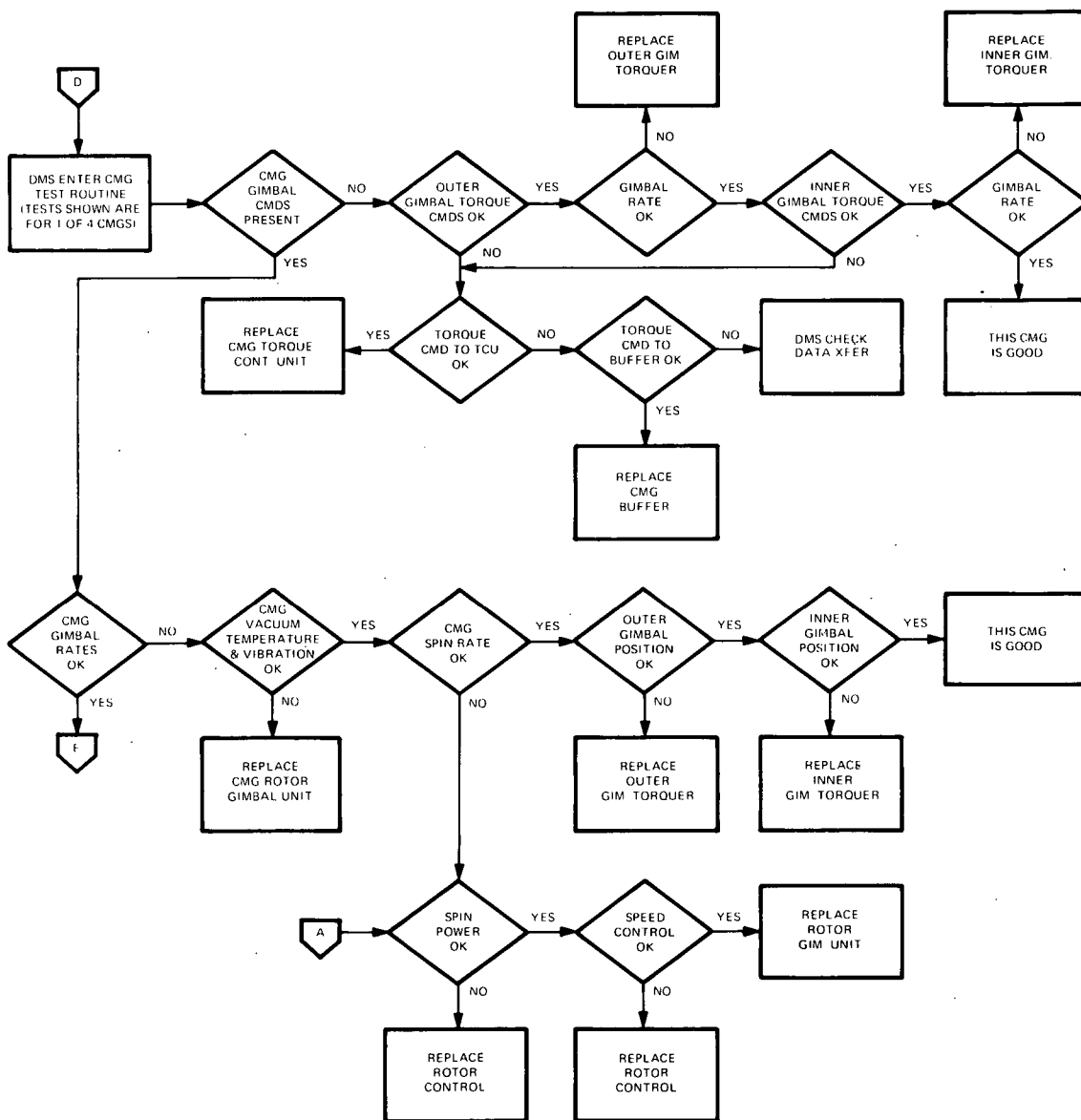
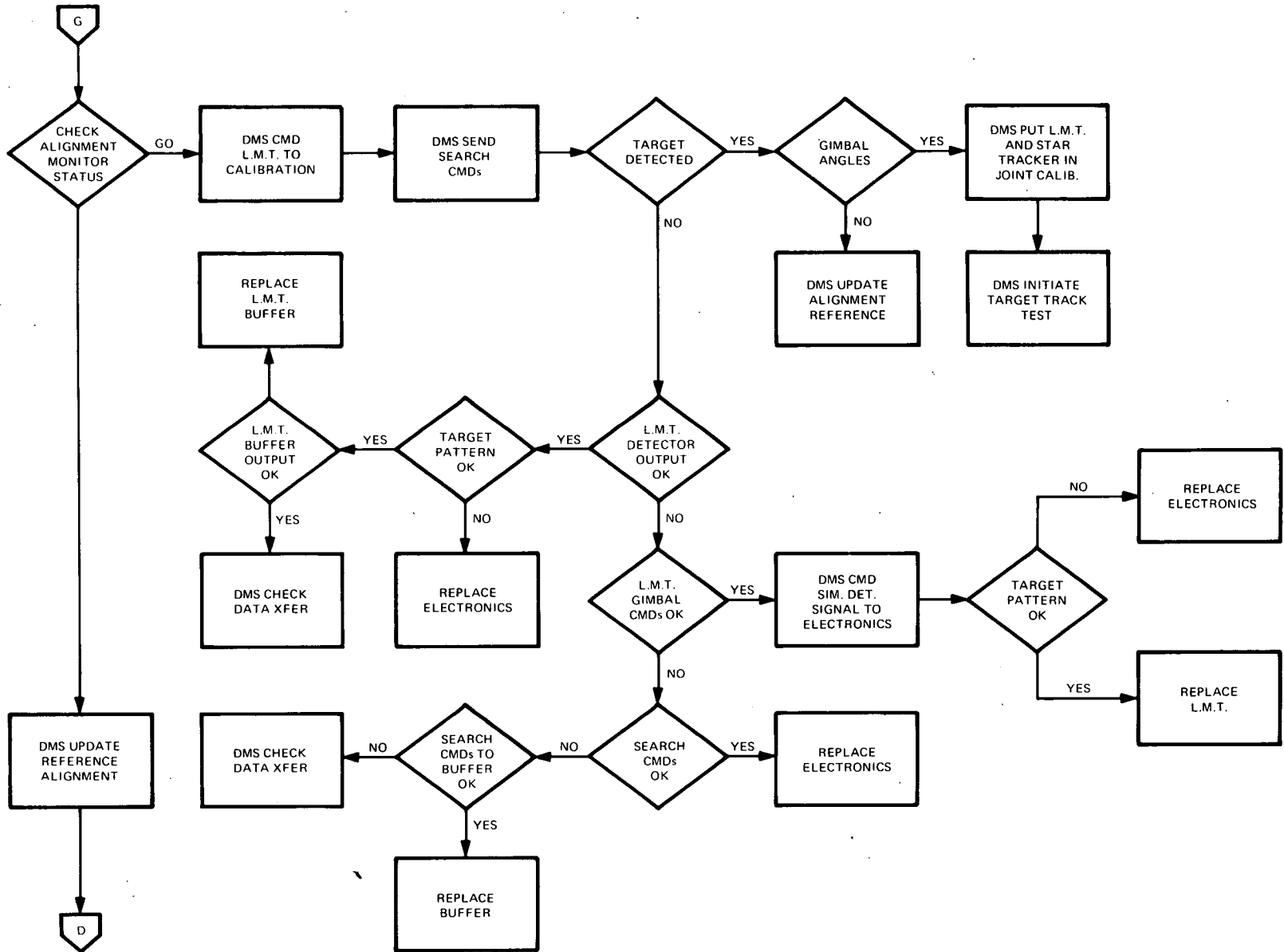


Figure 5-4. GN&C/DMS/PROP Integrated Test Flow (Sheet 2 of 4)

Figure 5-4. GN&C/DMS/PROP Integrated Test Flow (Sheet 3 of 4)



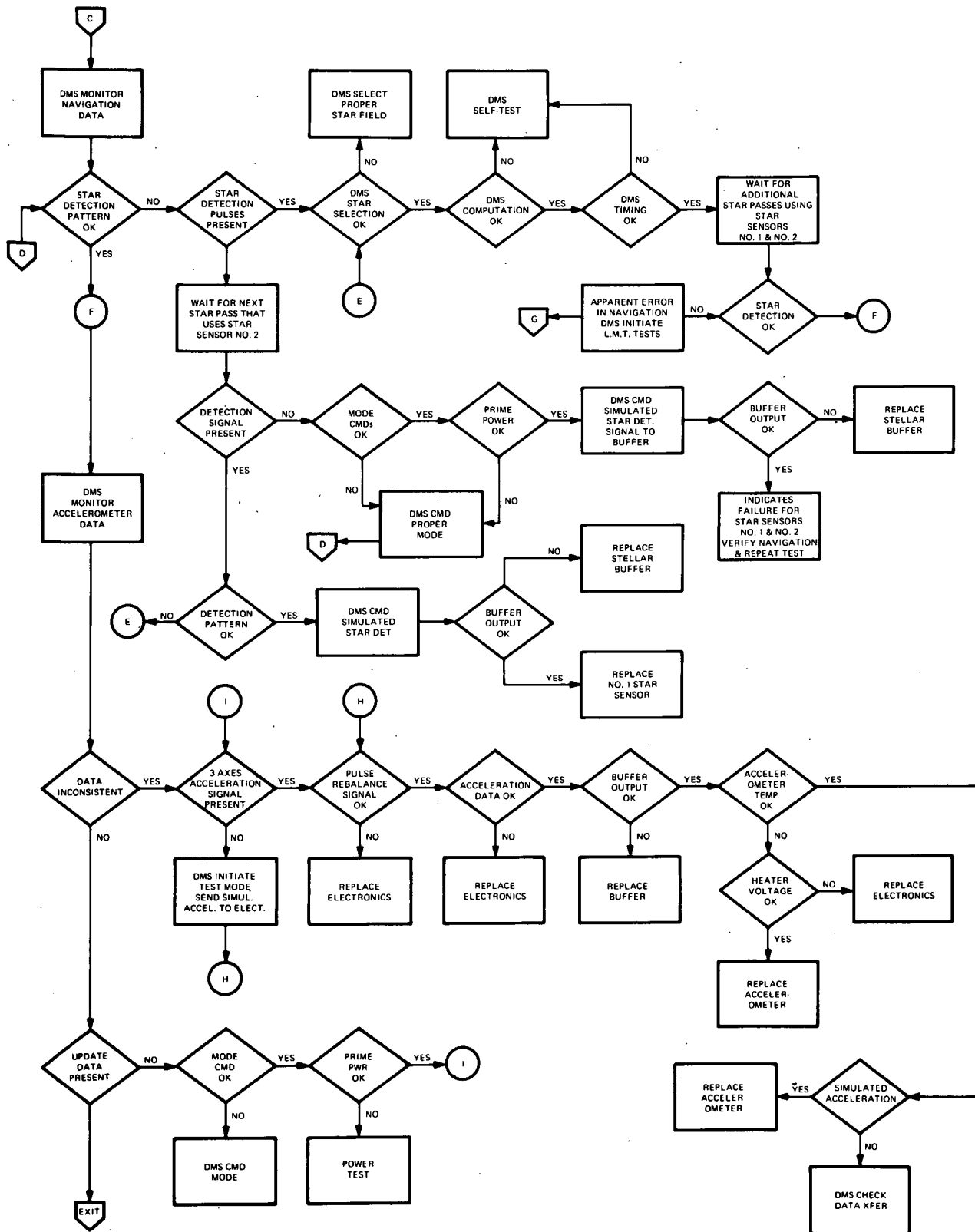


Figure 5-4.. GN&C/DMS/PROP Integrated Test Flow (Sheet 4 of 4)

pointed out that although the detail test sequence will be identical for all CMGs, the absolute value of the parameters such as torque commands, gimbal position, gimbal, rates will be different for all CMGs. In some cases, the test flow terminates in an instruction for the DMS to check data transfer. This instruction is intended to include all operations necessary to verify that the DMS is functioning as required to support the operational and test routine.

5.2.2 GN&C/DMS/COMM

The DMS has a functional interface with the GN&C and COMM Subsystems for the pointing and control of antennas. The GN&C sends navigation and attitude information to the DMS which in turn uses it to compute antenna pointing positions and slewing rates. Once computed, the DMS transfers these commands to the antenna actuators in the Communication Subsystem.

Localizing a malfunction to one of the three subsystems will be performed in a manner similar to that described in subsection 5.2.1. The DMS will verify receipt of proper attitude and navigation data from the GN&C Subsystem, check its capability to operate on and transform the data into appropriate antenna commands, and verify the transmission of the control data to the Communication Subsystem. Verification of proper response and operation of Communication Subsystem equipment will be aided by the switching and use of redundant transmitters and receivers.

5.2.3 GN&C - PROPULSION SUBSYSTEM INTERFACE

The Guidance, Navigation, and Control (GN&C) Subsystem operates in a closed-loop mode with the DMS and Propulsion Subsystem as elements of the loop. Electrical signals to activate appropriate Propulsion Subsystem high thrusters are provided by the GN&C jet drivers based upon control information computed by the DMS. Although the interface between the DMS and the GN&C is fairly complex, the GN&C - Propulsion Subsystem interface is not, and can easily be incorporated into tests defined for the Propulsion Subsystem.

Section 6

SOFTWARE

6.1 GENERAL CONSIDERATIONS

The recommended software checkout strategy involves a sequence of detecting faults, isolating faults to a failing LRU or LRUs, and reconfiguring the system to continue operation while the failures are being repaired.

This recommendation was developed by evaluating each subsystem with respect to the three general requirements of fault detection, fault isolation, and reconfiguration.

Fault detection incorporates both the recognition of failure occurrence, and the prediction of when a failure can be expected to occur. The Remote Data Acquisition Units (RDAUs) continually check selected test point measurements against upper and lower limits, and notify the executive on an exception basis when a limit is exceeded. This approach avoids occupying the central multi-processor with the low-information task of verifying that measurements are within limits.

Trend analysis is a fault detection technique recommended for predicting the time frame during which a failure can be anticipated. Data is acquired on a basis of time or utilization, and compared with previous history to determine if a "trend" toward degraded performance or impending failure can be detected.

Another checkout requirement evaluated for each subsystem is periodic testing. This type of test is provided to exercise specific components at extended time intervals or prior to specific events, to assure operational integrity. In the event that a failure is detected, the periodic test will isolate to the failing Line Replaceable Unit (LRU) and accomplish recertification after a repair operation.

Calibration of specific subsystem components will be required periodically, or subsequent to a repair and/or replace operation. The techniques involved are unique to the individual component; and, in some cases, require the acquisition of operational data.

Fault isolation is required when a fault is detected. When a particular fault provides an indication that a life critical failure has occurred, the fault isolation routines are automatically initiated. If the failure does not represent an immediate danger to the vehicle occupants, the crew is notified and they will initiate the fault isolation modules at their convenience.

The basic requirements of the fault isolation function is to analyze the available information relevant to a problem, and identify the LRU which is responsible for the anomaly.

Three basic approaches to meeting this requirement were considered. These are:

- Analyze each fault as an independent problem
- Analyze each fault with a state matrix which defines the possible error states of the subsystem
- Associate each fault with a specific subsystem, and evaluate that subsystem in detail

The third approach was selected on a basis of software commonality and cost effectiveness. The complexity associated with the testing can be reduced by localization of the logic associated with the analysis of the subsystem in a unique package. The software commonality will result in reduced software development and maintenance costs, while increasing the reliability of the software.

The fault isolation software is structured modularly for compatibility with the hardware structure of the subsystem. Checkout modules evaluate the performance of a specific portion of the subsystem. A convenient division for this modular structure is at the assembly level or functional area. A program module which can determine and control the sequence in which these checkout modules are executed is also required for each subsystem.

Subsequent to fault detection, the software associated with the subsystem which is most likely to contain the error will be activated.

The subsystem software will analyze the error indication, and initiate a sequence of checkout modules to isolate the problem. If successful, the crew is notified regarding the Line Replaceable Unit (LRU) to be replaced. If an error cannot be identified, the crew is informed of the situation and has an option to execute the periodic test of the subsystem.

After a fault has been isolated, reconfiguration software restores the functional capability of the subsystem. This is most commonly accomplished by exchanging a redundant element for the failing unit, or by defining an alternate path to accomplish the required function.

The Task 2 Final Report of the basic onboard checkout techniques study provides descriptions of the software requirements, definitions and design in addition to detailed flow charts of specific checkout routines.

6.2 SPACE STATION SUBSYSTEM

The Guidance, Navigation and Control (GN&C) Subsystem checkout programs are used to monitor GN&C Subsystem test points in order to verify the proper operation of the functional assemblies of which it is made. Cognizance is taken of the mode of the GN&C Subsystem by utilizing data prepared by the GN&C Application Programs. When a fault indication is detected, isolation is performed by logically combining the measurements taken from test points of the subsystem. Fault detection is initiated and performed without crew assistance. This does not preclude crew control, however, since a test module may be initiated from the display console keyboard or by ground command at any time. In addition, the rate at which the monitoring modules are initiated may be altered in a similar manner.

The functions identified are those for fault detection, fault isolation, trend analysis, reconfiguration, and calibration. They are implemented in a combination of hardware, multi-level executive, and high-level language programs. The modular programs and executive services are multi-purposed and can be invoked by the crew, ground personnel, or other programs.

The GN&C Checkout Programs provide for fault detection, trend analysis, fault isolation, reconfiguration, and calibration by a combination of executive services, high level language programs, and coordinated hardware utilization.

The modules used for fault isolation, reconfiguration, and calibration are capable of being initiated by crew, ground, or another module. Before proceeding on an analysis of subsystem test points, the subsystem mode is ascertained in order to determine which analysis modules should be employed and how the analysis should be performed. Checkout module performance is valid whether initiated as a result of an RDAU limit check, a crew or ground command, or by the Pacer (a software module which automatically initiates programs at a prescribed rate). A diagram of the Guidance, Navigation and Control Subsystem is shown in Figure 6-1.

Figure 6-2 reflects the functional breakdown of the subsystem and the hierarchical relationship which exists between the various assemblies.

Figure 6-1. Guidance, Navigation and Control Subsystem

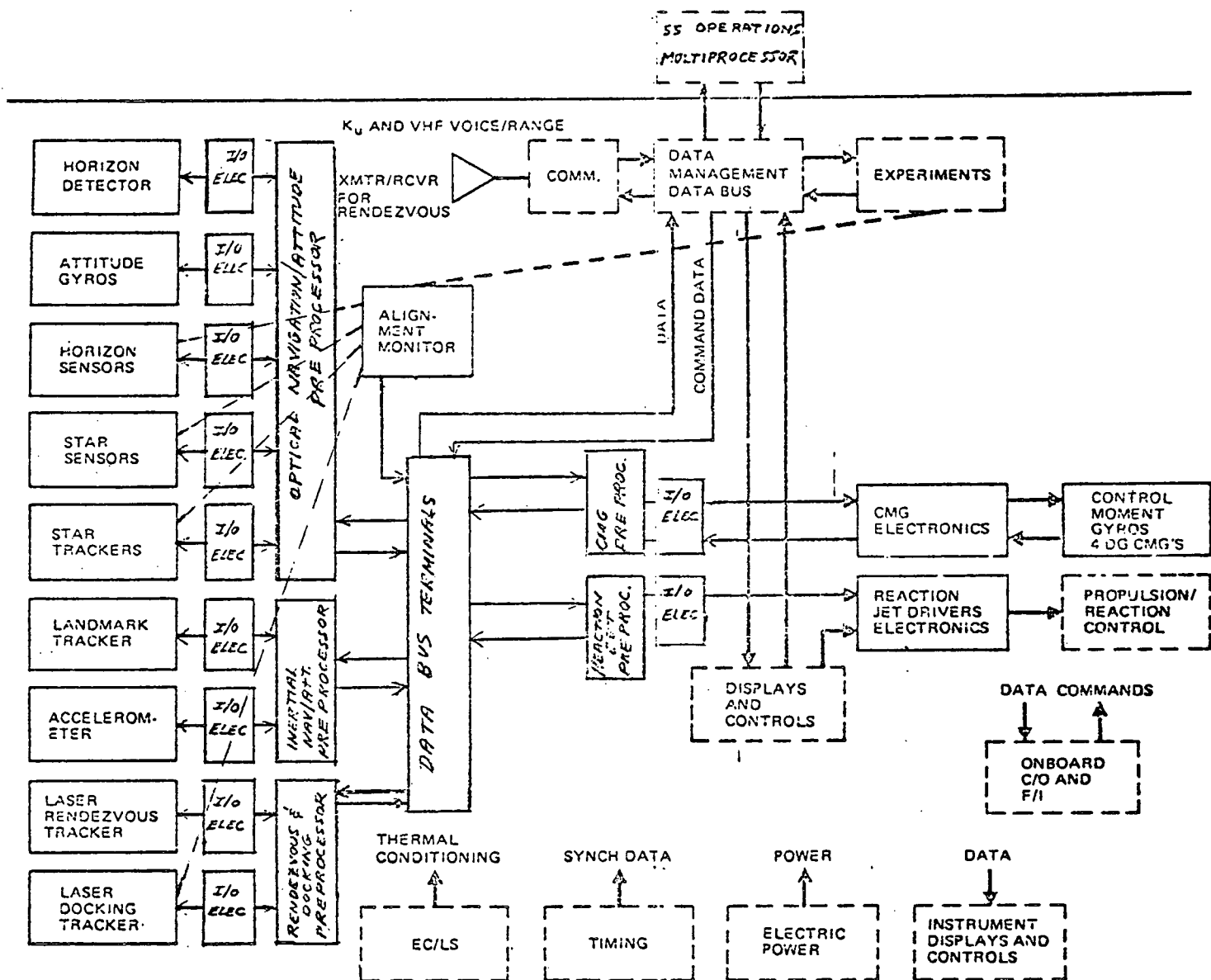
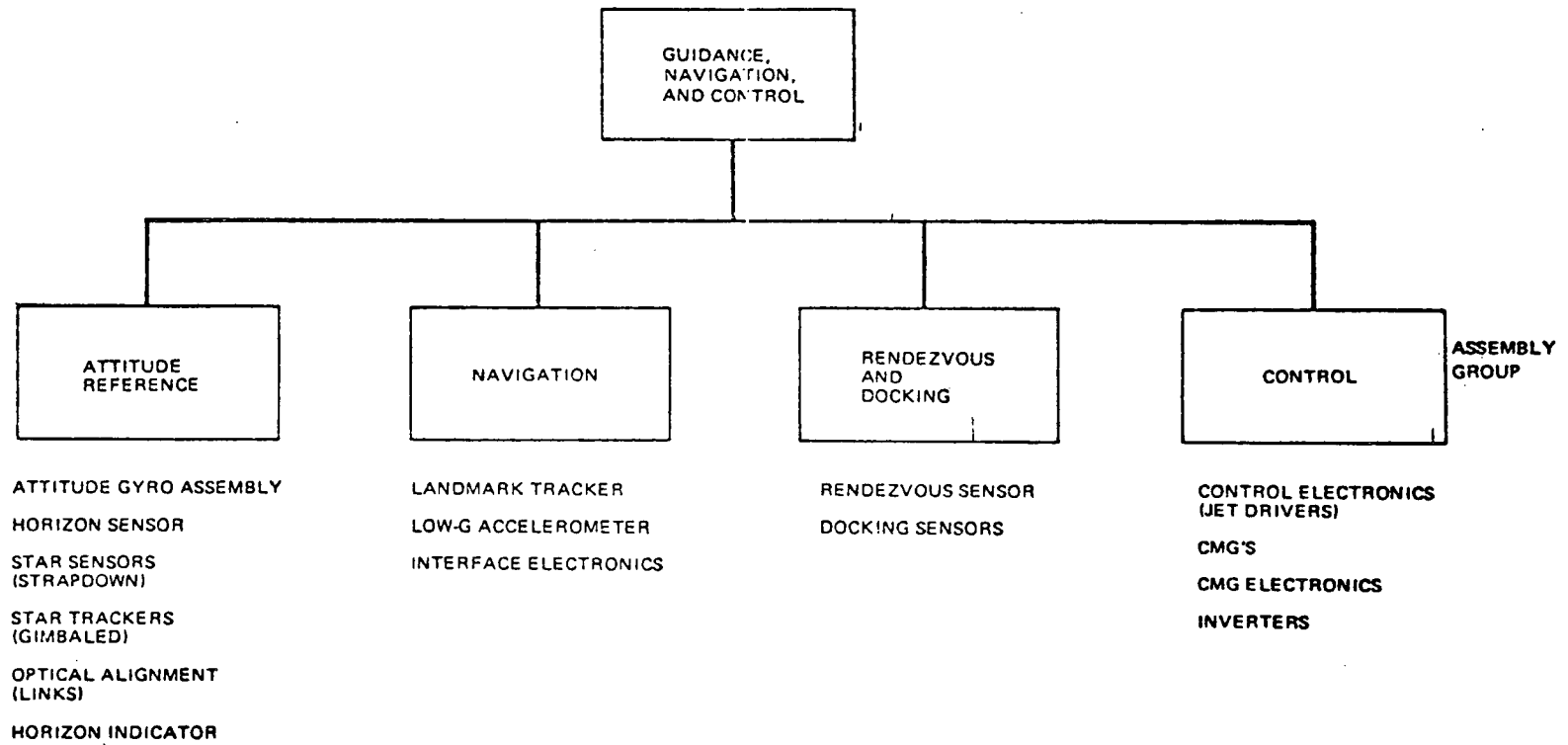
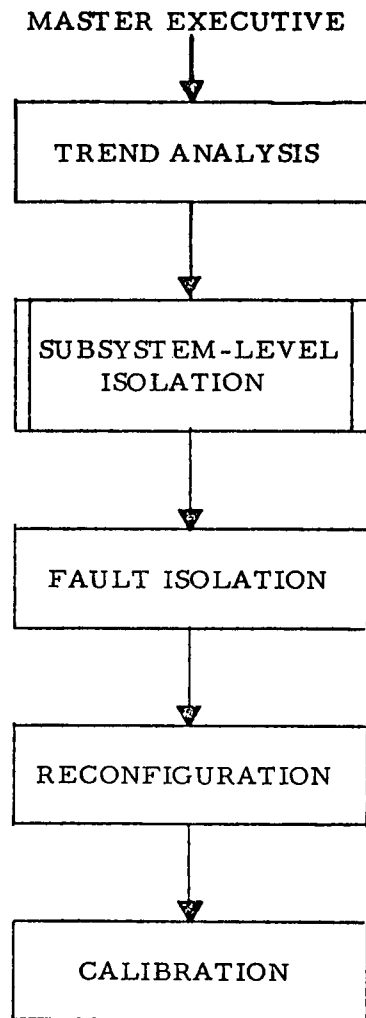


Figure 6-2. GN&C Subsystem Assembly Configuration



The GN&C Checkout Program structure is outlined in the following chart:



All functions are initiated as independent modules by the master executive program. When a module requires another program to be executed, it requests this of the master executive.

6.2.1 SYSTEM REQUIREMENTS

The GN&C System requires that trend analysis be performed and used as a fault detection method. In addition, interface with crew and ground is required upon detection of an unfavorable trend, so that potential resupply aspects can be considered. Operational data will be used where appropriate for checkout purposes.

The GN&C Checkout Programs are written in a high level language so that development and alteration by professionals other than programmers will be feasible. The programs will interface with a multi-level executive, the lowest level of which will also serve non-checkout programs. Upper levels of the executive will perform services unique to the checkout mission.

Note that interface between the Data Management Subsystem and the GN&C Subsystem (see Figure 6-3) is accessed only through the Master Executive. Checkout programs may interface either directly or indirectly with an executive level.

Fault detection will be accomplished by hardware under the control of software, by GN&C application programs, and by trend analysis programs. The most common method will be hardware under control of software. Limits are stored in the memory of the Remote Data Acquisition Units (RDAUs) which continuously check test points, and interrupt the multiprocessor if an out-of-limit signal is received. The rate at which the RDAU checks limits meets or exceeds the highest rate requirement for fault detection sampling.

While continuous orbital monitoring will be performed by RDAU hardware under software executive control, periodic checks will be performed by using the same modules employed during fault isolation.

6.2.2 OPERATIONAL REQUIREMENTS

The GN&C checkout modules are required to perform caution and warning, trend analysis, calibration, fault isolation to the LRU level, and reconfiguration of the GN&C Subsystem with a modular design which allows employment of various program modules in a variety of configurations upon initiation by RDAU interrupt, crew, ground, Pacer, or other programs. The fault detection control and trend analysis functions are implemented by extensive use of executive modules. The higher level language is used for the fault isolation, reconfiguration, and calibration functions with executive support in the areas of mode analysis and data base management.

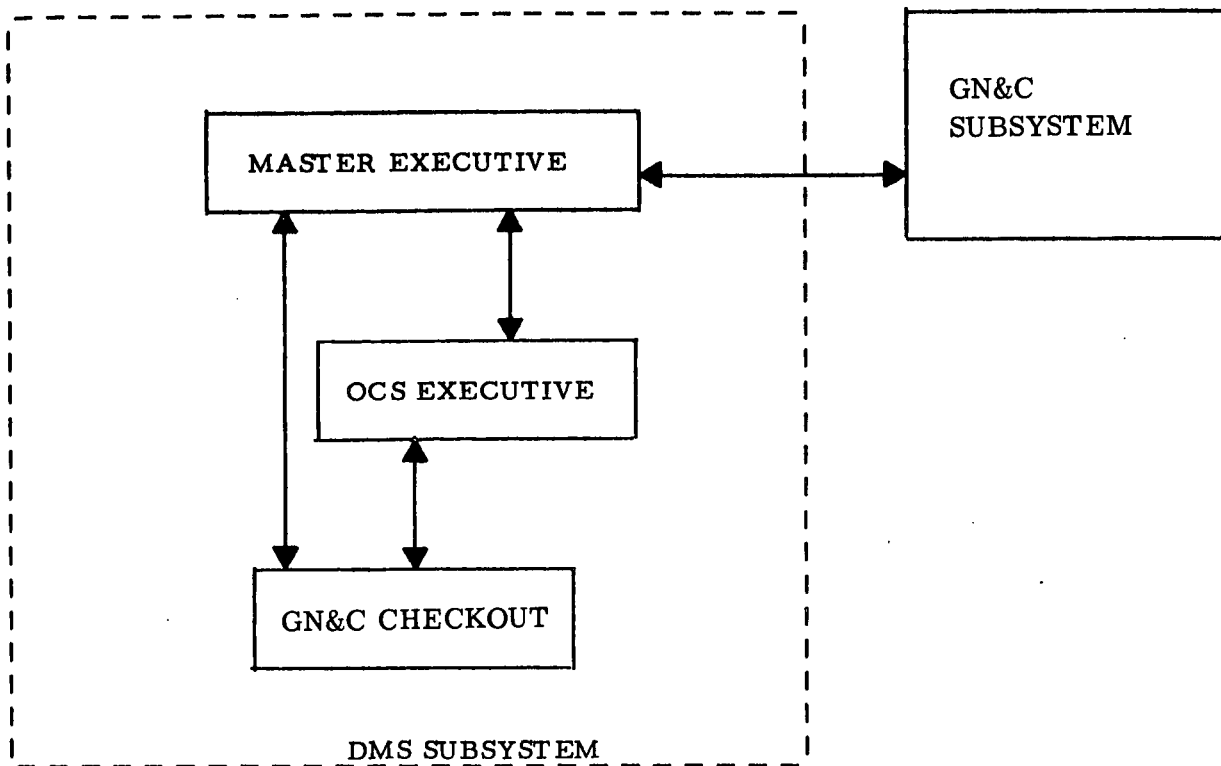


Figure 6-3. Executive and Subsystem Interfaces

6.2.2.1 Fault Detection Function

Since the fault detection function is operationally implemented in the RDAU hardware, this section discusses the control of the RDAU limit check feature. The contents of RDAU memory must be redundantly maintained in auxiliary storage so that the secondary RDAU may be initialized if the primary fails.

Input to the fault detection control function consists of the command to change RDAU limits, a mode table, and a limit table. Output consists of the mode table, limit table, the RDAU memory, and displays.

Information processing takes place in the OCS Executive, and consists of changing the RDAU channel mask to enable or disable interrupts caused by out-of-limit signals, changing the limits, and updating the mode and limit tables accordingly. The extensive involvement with executive table formats makes implementation as an executive service more attractive than implementation in a higher-level language.

Limit check specifications are made regarding a symbolic test point address. The fault detection control function translates this into specific RDAU memory changes for both the primary and secondary RDAUs. In doing so, it must reference the symbolic address translation, configuration, and RDAU memory tables.

A flowchart of the fault detection control function is shown in the Task 2 Final Report.

6.2.2.2 Fault Isolation Function

Primary logic control of isolation programs is accomplished by the language TOOL. Those services and functions which are common to fault isolation in other subsystems are provided as executive services.

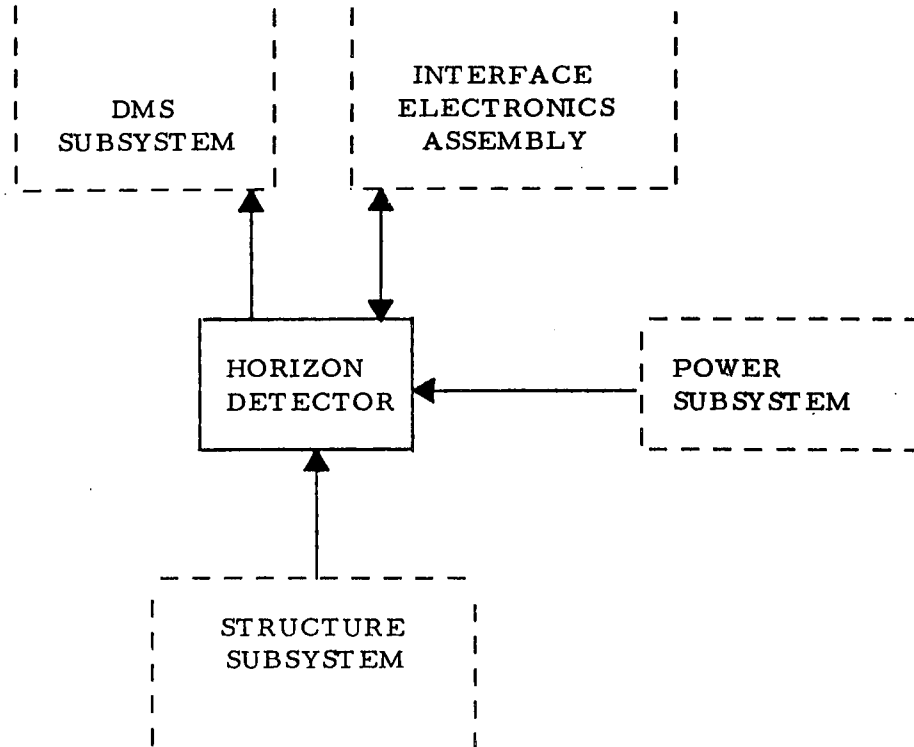
Input to the fault isolation function consists of RDAU interrupts, crew initiation, initiation by other programs, the symbolic address of the test points, test point measurements, data being managed by application programs, and the mode table.

Output from the fault isolation function consists of stimuli, commands, displays, mode table, and parameters for the reconfiguration module.

Fault isolation processing consists of determining whether the mode of the assembly allows the test to proceed, allowing a mode change if necessary, evaluating the interfaces supplied to the assembly under test, and evaluating the LRUs of the assembly. LRU evaluation involves an examination of interfaces, similar to that done for the next higher assembly; consequently, the order in which LRUs are tested is important. The modules are designed to provide verification on an as-required or periodic basis, such as just prior to artificial G mode.

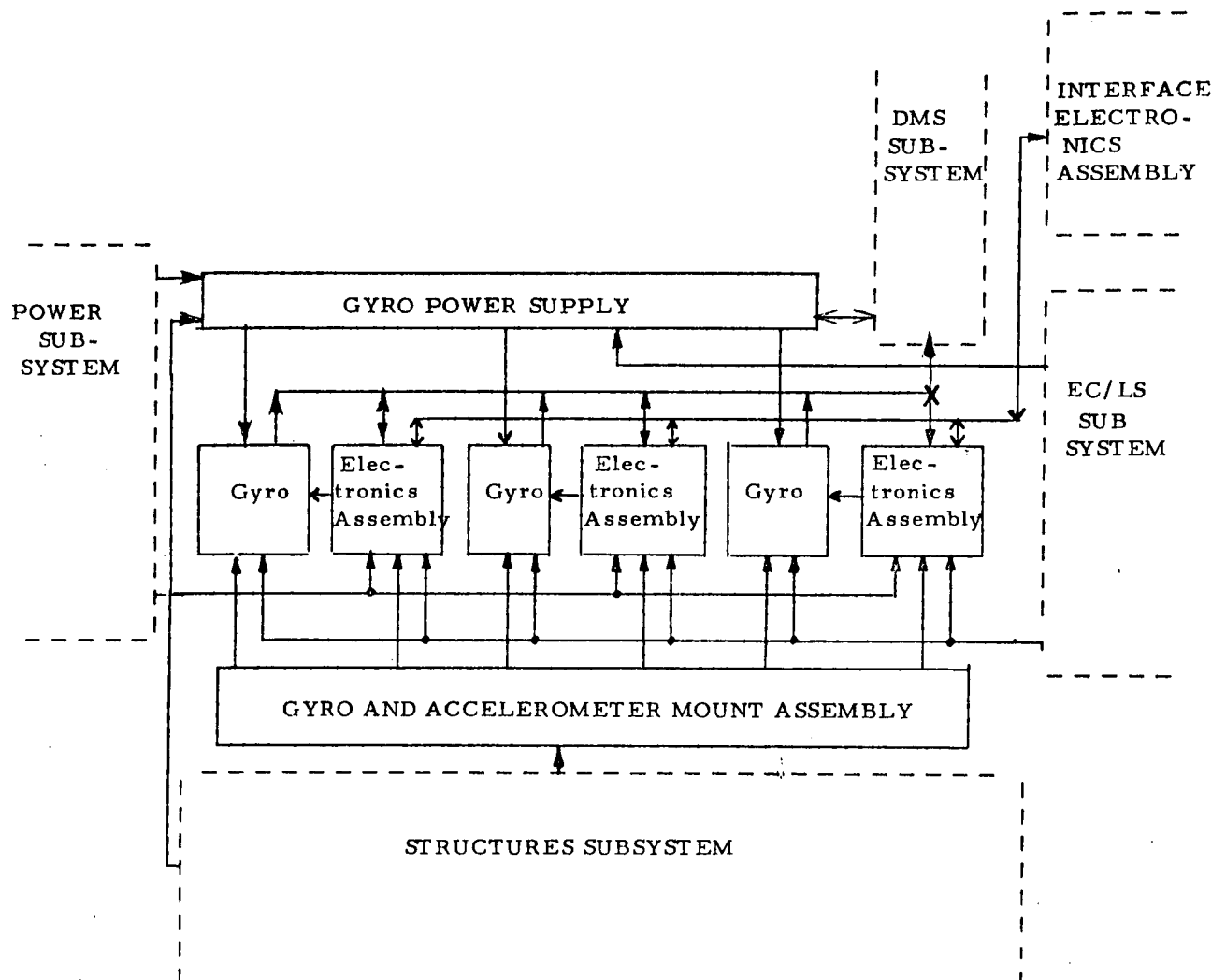
Of particular importance in the isolation of failed Line Replaceable Units (LRUs) is the examination of interfaces between the assembly under analysis and other assemblies. In Figures 6-4 through 6-6, examples of interfaces which are important during fault isolation are shown. Prior to evaluating the performance of any assembly, it is necessary to make sure that its supporting interfaces are within tolerance. The approach required for GN&C fault isolation, showing the relationship between the mode, interface, and assembly analyses appears in Figure 6-7.

Information reflecting the attributes of fault isolation modules for each GN&C Subsystem assembly appears in Table 6-1.



Required	2
Redundant	0
Total	2

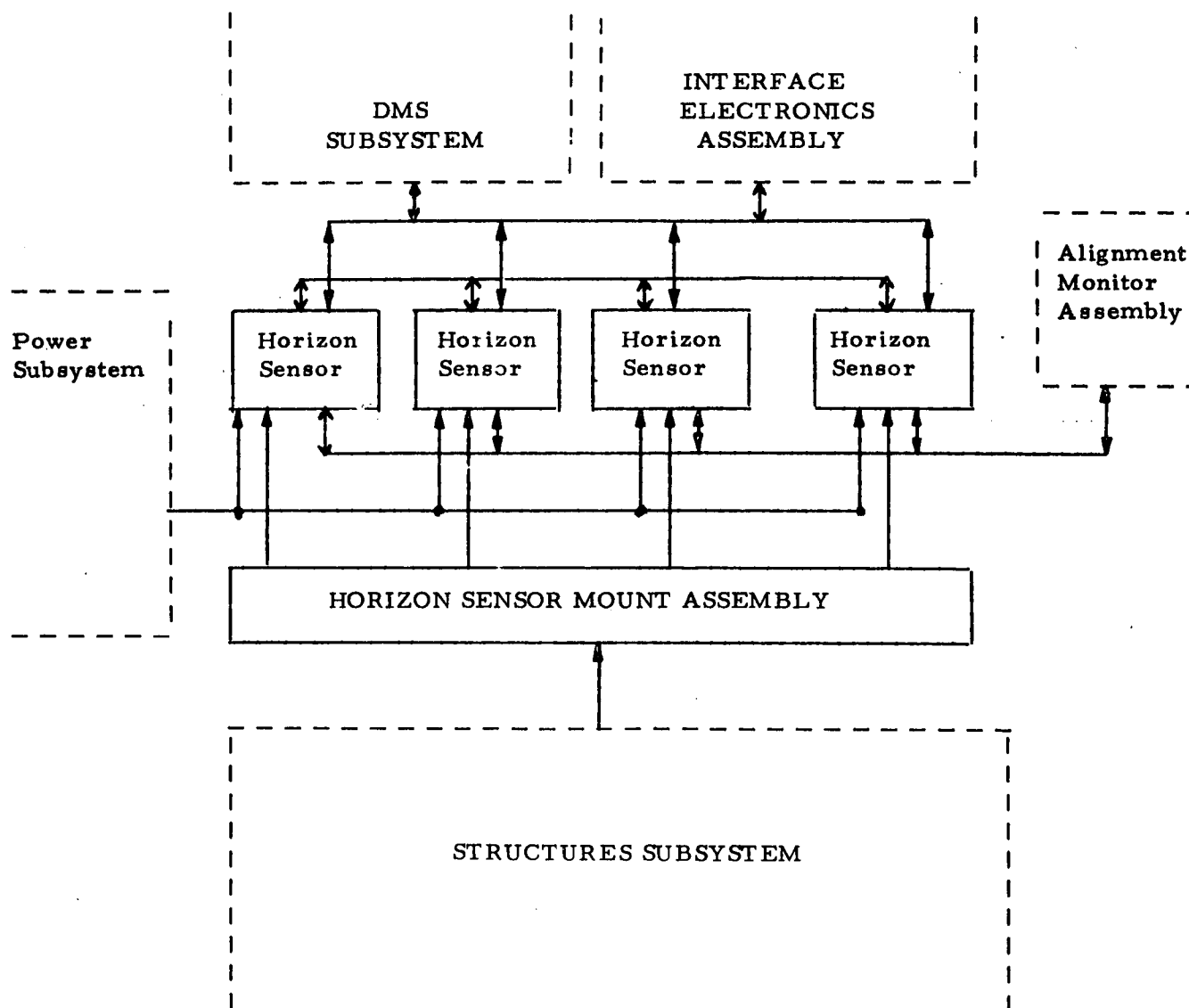
Figure 6-4. LRU Interface Diagram Horizon Detector Assembly



NOTE: One-Half of the Assembly (symmetrical) shown.

Required	1
Redundant	0
Total	1

Figure 6-5. LRU Interface Diagram, Attitude Gyro Assembly



Required	1
Redundant	0
Total	1

Figure 6-6. LRU Interface Diagram, Horizon Sensor Assembly

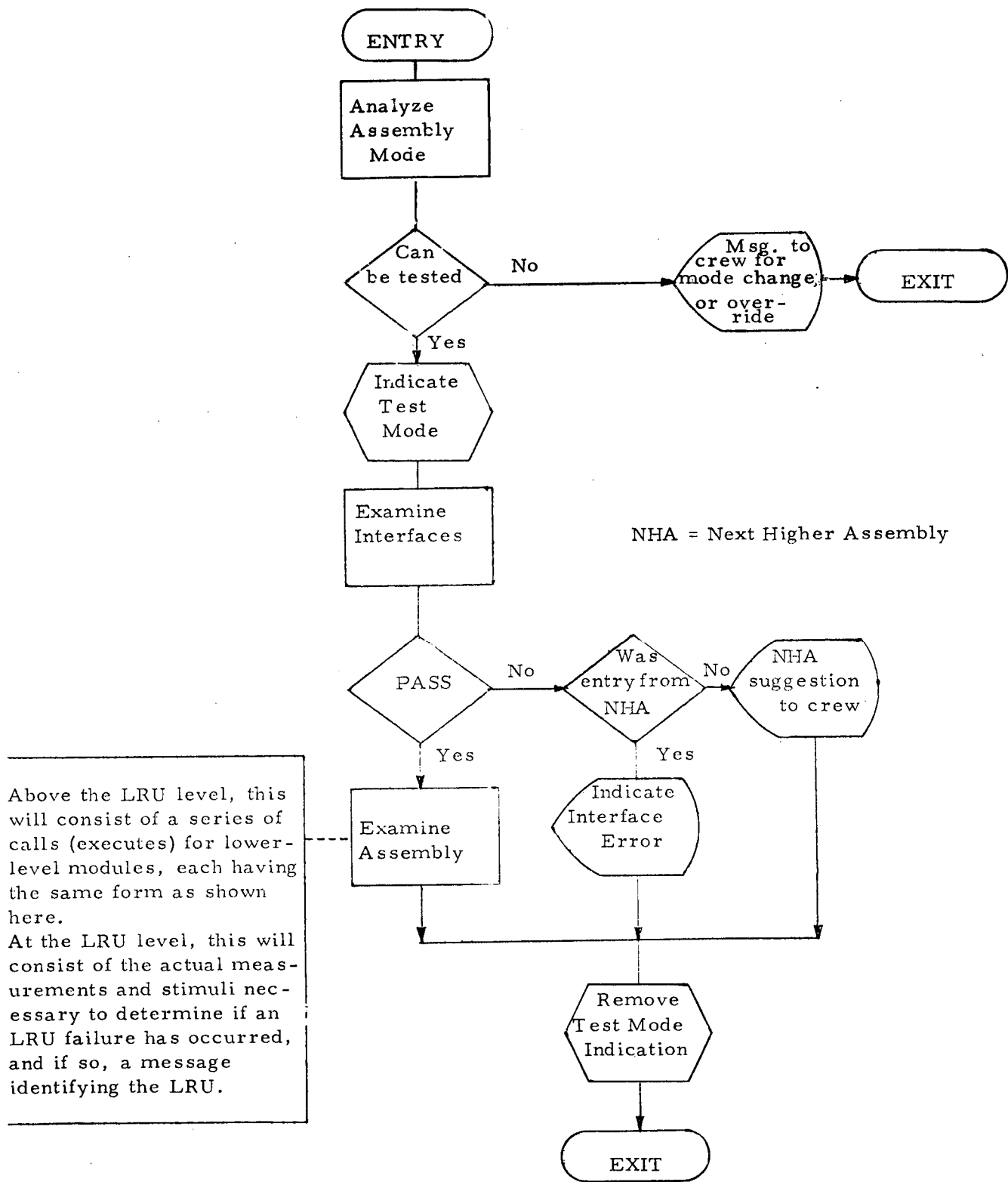


Figure 6-7. General Fault Isolation

Table 6-1. Fault Isolation and Periodic Check Requirements

		Attributes of the F.I. Program												
		Exclusive Control	Changes Status	Acquires Apl. Data	Changes Apl. Data	Acquires Exec. Data	Changes Exec. Data	Cycles Assembly Mode	Requires Stimuli	Digital Readings	LRU Sequence Imp.			
A S S E M B L Y	Horizon Detector	x	x		x			x						
	Attitude Gyro	x	x		x		x	x		x				
	Star Sensor	x	x		x		x							
	Star Tracker	x	x			x	x		x	x				
	Landmark Tracker	x	x		x		x	x	x	x				
	Low-G Accelerometer	x	x	x	x					x				
	Rendezvous Tracker	x	x			x	x	x	x	x				
	Docking Tracker	x	x		x		x	x	x	x				
	Sensor Alignment Monitor	x	x	x	x					x				
	Experiment Alignment Monitor	x	x	x	x			x	x					
	Interface Electronics	x	x		x			x		x				
	Control Moment Gyro				x				x	x				
	CMG Electronics	x	x		x		x	x						

In preparing the table, the following considerations were applied to the fault isolation for each assembly:

- Is exclusive control of the assembly under analysis required, thus precluding operational use during fault isolation?
- Is the status of the assembly altered during analysis?
- Is it necessary to make use of data which is managed by application programs?

- Must the application data be altered? This consideration is mutually exclusive of the one immediately above.
- Is it necessary to make use of data maintained by the executive?
- Must the executive data be altered? (Mutually exclusive)
- Is it necessary to cycle the assembly through various modes of operation during fault isolation?
- Are stimuli required during analysis?
- Are digital readings used, as contrasted with analog or bi-level?
- Is the sequence in which the LRUs of the assembly are examined important?

Fault isolation examples for the horizon detector, attitude gyro, horizon sensor, star sensor, star tracker, and rendezvous tracker are shown in Figures 3-21 through 3-30 of the Task 2 Final Report.

6.2.2.3 Trend Analysis Function

Trend analysis is used on selected GN&C parameters for the detection of degraded performance or impending failure.

Input to the trend analysis function consists of RDAU interrupts, measurements, the Pacer, and real time. Output consists of caution and warning displays, trend table data, and fault isolation parameters.

The parameter is measured and the time of measurement is obtained. These values are combined with a pre-determined number of previous values to form a set of X-Y coordinates which could be plotted on a graph depicting parameter value versus time. Exponential smoothing of the data is performed, and extrapolation estimates are calculated to determine if the trend is approaching a caution or warning condition; if prior to the next measurement cycle the parameter will be out of limits, or that a failure may occur for the LRU between resupply event i and resupply event i+1.

Trend analysis modules exist for each of the following GN&C Subsystem assemblies:

- Attitude Gyro
 - gyro case temperature
 - gyro heater voltage

- Accelerometer
 - accelerometer temperature
 - accelerometer heater voltage
- Laser Rendezvous Tracker
 - tracker transmitter power monitor
 - tracker receiver energy monitor
- Laser Docking Tracker
 - tracker transmitter power monitor
 - tracker receiver energy monitor
- Jet Driver
 - driver inputs
- Control Moment Gyro
 - spin power monitor
 - vibration monitor
 - bearing temperature monitor
 - vacuum monitor

The following trend analysis methods are utilized by GN&C checkout:

- Integration, with respect to time over a fixed time interval, and comparison of the integral with a fixed limit. This method is employed with the attitude gyro and accelerometer assemblies.
- An average of N samples taken during a particular phase of operation, with the average compared to that acquired previously. This method is employed with the laser rendezvous tracker and docking tracker assemblies.
- A count of the number of operations over a fixed time interval and comparison with a fixed limit. This method is employed with the jet driver assembly.
- Periodically sample for a time interval which is small compared to the period. This method is employed with the control moment gyro assembly. The samples are averaged, adjusted for trend, and used to calculate the estimated time of failure, if any.

Figures 3-31 through 3-34 of the Task 2 Final Report contain logic flow-charts for the time integration, moving average, operations count, and periodic sample methods of trend analysis employed for the GN&C Subsystem.

6.2.2.4 Reconfiguration Function

The reconfiguration function keeps track of the use of primary and redundant assemblies by using symbolic assembly identification. This implies that the application programs reference assemblies using the same symbology.

Inputs consist of the symbolic identity of the failed LRU, the configuration table, and the mode table. Identification of the LRU may come from the crew, instead of from the fault isolation function.

Outputs consist of changes to the configuration table, changes to the mode table, crew displays, mode commands, and parameters to the calibration function.

Information processing consists of changing the modes of both the replaced and the replacement assemblies, and updating the configuration table to show the relationship with the next higher and next lower assemblies. The interchanged assemblies are commanded to change modes as appropriate; and the mode table is changed to reflect the status in preparation for future fault isolation activities.

The reconfiguration function of GN&C checkout is concerned with alterations to the GN&C Subsystem, and the data base alterations necessary to track these changes. Therefore, a combination of mode commands and table maintenance activities are involved. The function involves extensive use of executive services for data base management, while utilizing bi-level and digital stimulus points in order to activate/de-activate the LRUs involved in reconfiguration.

If the spare is installed, reconfiguration can be accomplished automatically. If a spare is not available, the status of the containing assembly is altered to reflect the fact that it is disabled. If the spare is on board, but requires crew action, notification of a failure rate monitor may take place in order to ensure that the repair rate will exceed the failure rate.

The logic flow for the reconfiguration function is shown in Figure 6-20.

6.2.2.5 Calibration Function

Calibration may be employed periodically after repair, or as a result of replacing a failed assembly. The techniques involved are unique to the individual assemblies, and in some cases involve the acquisition of data managed by application programs.

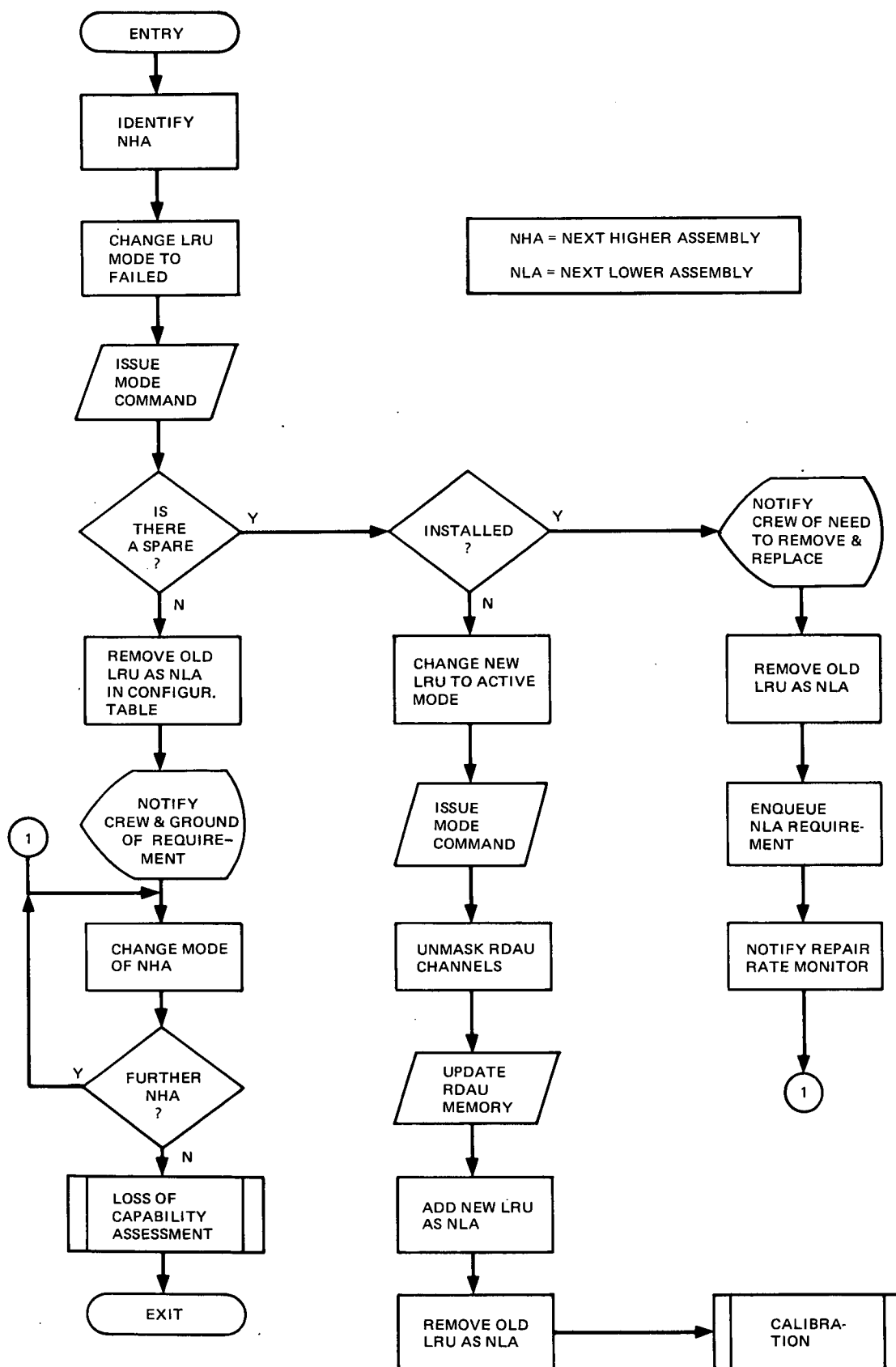


Figure 6-20. Reconfiguration

Input to the calibration function consists of parameters supplied by the crew, information passed by the reconfiguration function, calibration tables, and operational data. Output consists of changes to the operational data tables and crew communication.

Information processing includes the employment of other functional GN&C assemblies for reference purposes, and changing the calibration references for application programs. As an example, a reading of 3.27 volts may correspond to a zero degree reference for the new assembly; whereas for the assembly which failed, a reading of 2.98 volts was the zero reference for the replaced assembly.

The calibration function is concerned with the data base management involved when an LRU is replaced by crew action, as well as the stimuli and crew interaction which may be involved in actual calibration of certain GN&C LRUs. The calibration function is, therefore, used during replace operations; whereas the reconfiguration function discussed above is concerned with remove operations.

The calibration function may be invoked by the crew, or automatically by the reconfiguration function for certain installed spares.

The logic flow for the calibration function is shown in Figure 6-21.

6.2.3 INTERFACE REQUIREMENTS

The GN&C checkout program requires services of, and is initiated by, the Executive program. Any interfaces to other programs, or data managed by other programs, is obtained through the executive. When crew or ground initiation is required, this is done with the executive serving as an interface.

The checkout function interfaces are shown in Figure 6-22. The Caution and Warning function examines a test point criticality table for each measurement detected to be out of limits, and provides required notification on the appropriate display. This function is performed by the OCS Executive which receives control from the interrupt handler of the Master Executive, from a trend analysis module, or from an application program.

The OCS Executive is also involved during fault isolation in an analysis of the mode of the assembly to be tested, and an analysis of the modes of the interfacing assemblies.

Detailed interfaces between GN&C Checkout Program functions and specific Data Management Subsystem (DMS) elements and tables are shown in Figures 3-38 through 3-42 of the Task 2 Final Report.

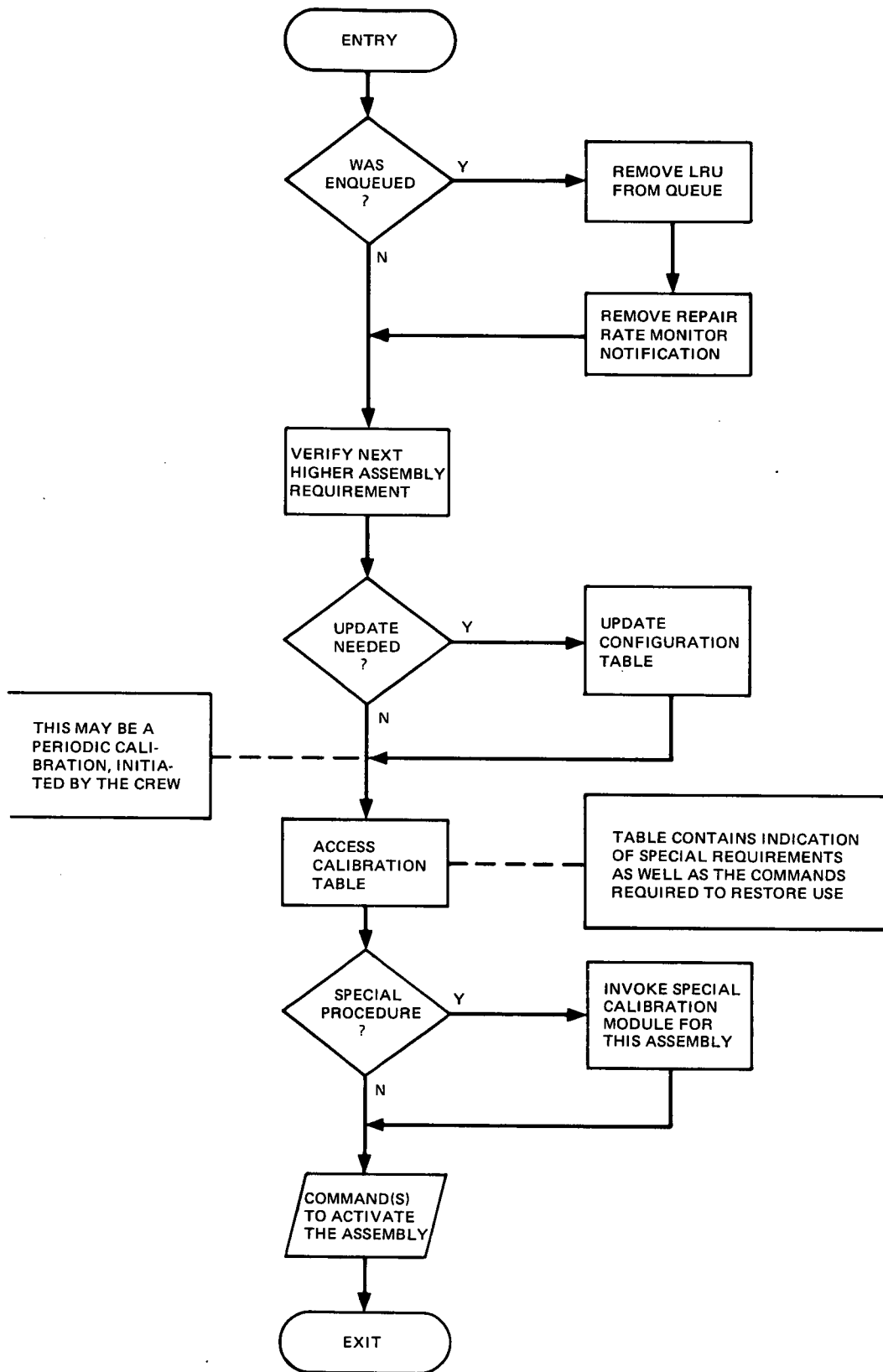


Figure 6-21. Calibration

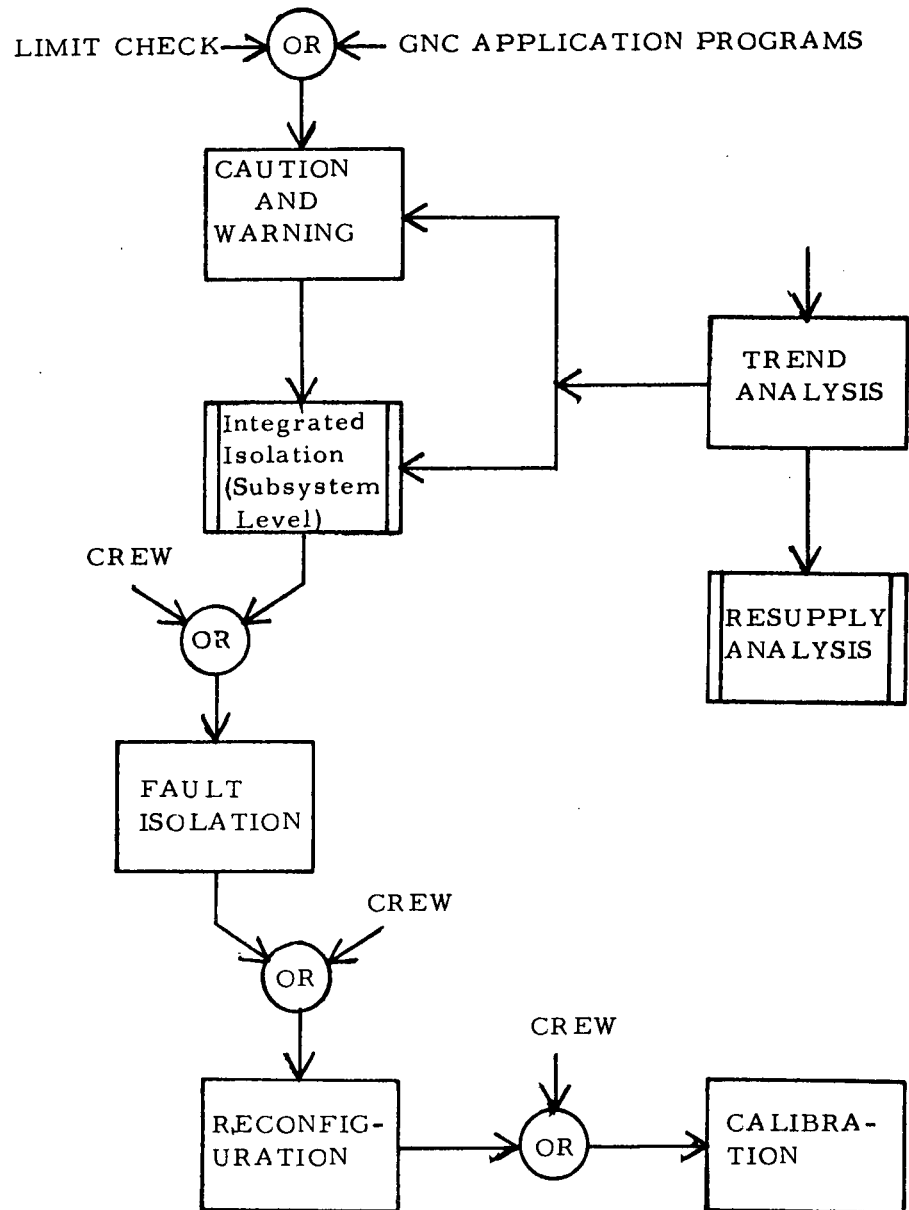


Figure 6-22. GN&C Checkout Function Interfaces

Section 7

MAINTENANCE

There are two aspects of maintenance which entered into the basic study. Basic maintenance concepts were provided as part of the baseline resulting from the Phase B Space Station study; they are discussed in subsection 7.1 below. Additionally, one of the study tasks was aimed at implementation of an onboard electronics maintenance capability. The results of that task are summarized in subsection 7.2.

7.1 BASELINE MAINTENANCE CONCEPTS

Maintenance concepts defined for Space Station subsystems are intended to facilitate their preservation or restoration to an operational state with a minimum of time, skill, and resources within the planned environment.

7.1.1 GENERAL SPACE STATION MAINTENANCE POLICY

It is a Space Station objective that all elements be designed for a complete replacement maintenance capability unless maintainability design significantly decreases program or system reliability. This objective applies to all subsystems wherever it is reasonable to anticipate that an accident, wearout, or other failure phenomenon will significantly degrade a required function. Estimates of mean-time-between-failure, or accident/failure probability, are not accepted as prima facie evidence to eliminate a particular requirement for maintenance. Should the accident/failure probability be finite, the hardware is to be designed for replacement if it is reasonable and practical to do so.

As a design objective, no routine or planned maintenance shall require use of a pressure suit [either EVA or internal vehicular activity (IVA)] . Where manual operations in a shirtsleeve environment are impractical, remote control means of affecting such maintenance or repairs should be examined. However, EVA (or pressure suit IVA) is allowable where no other solution is reasonable, such as maintenance of external equipment.

Time dependency shall be eliminated as a factor of emergency action insofar as it is reasonable and practical to do so. This includes all program aspects of equipment, operations, and procedures which influence crew actions. When time cannot be eliminated as a factor of emergency action, a crew convenience period of 5 minutes is established as the minimum objective. The purpose of the convenience period is to provide sufficient time for deliberate, prudent, and unhurried action.

7.1.2 ONBOARD MAINTENANCE FACILITY CONCEPTS

In addition to OCS/DMS capabilities, other onboard maintenance support facilities provided on the Space Station include:

- Special tools for mission-survival contingency repairs such as soldering, metal cutting, and drilling, as determined from contingency maintenance analyses, although repairs of this type are not considered routine maintenance methods.
- Protective clothing or protective work areas for planned hazardous maintenance tasks (such as those involving fuels, etc.).
- Automated maintenance procedures and stock location data for both scheduled and unscheduled maintenance and repair activities.
- Real-time ground communication of the detailed procedures, update data, and procedures not carried onboard.
- Onboard cleanroom-type conditions by "glove box" facilities compatible with the level at which this capability is found to be required.
- Maintenance support stockrooms or stowage facilities for spares located in an area that provides for ease of inventory control and ready accessibility to docking locations or transfer passages.

7.1.3 SUBSYSTEM MAINTENANCE CONCEPTS

Space Station subsystems utilize modular concepts in design and emplacement of subsystem elements. Subsystem modularity enhances man's ability to maintain, repair, and replace elements of subsystems in orbit. Providing an effective onboard repair capability is essential in supporting the Space Station's ten-year life span since complete reliance on redundancy to achieve the long life is not feasible. The need for a repair capability, in turn, requires that a malfunction be isolated to at least its in-place remove-and-replace level. The level of fault isolation is keyed to the LRU, which is the smallest modular unit suitable for replacement. The identification of subsystem LRUs is addressed as a separate, but interdependent, part of the Onboard Checkout Study.

Specific subsystem maintenance concepts, of course, depend upon examination of the subsystems. These concepts are discussed in subsequent subparagraphs. General subsystem-related maintenance guidelines that have been established for the Space Station are:

- It is an objective to design so that EVA is not required. However, EVA may be used to accomplish maintenance/repair when no other solution is reasonable.
- Subsystems will be repaired in an in-place configuration at a level that is acceptable for safety and handling, and that can be fault-isolated and reverified by the integrated OCS/DMS. This level of maintenance is referred to as line maintenance and the module replaced to effect the repair is the LRU.
- A limited bench-level fault isolation capability will be provided on the Space Station, but is only intended for contingency (recovery of lost essential functions beyond the planned spares level) or for development purposes. Limited bench-level support is also provided in the form of standard measurement capabilities which are used primarily to reduce the amount of special test equipment required.
- Subsystem elements, wherever practical, will be replaced only at failure or wearout. Limited-life items that fail with time in a manner that can be defined by analysis and test will be allowed to operate until they have reached a predetermined level of deteriorated performance prior to replacement. Where subsystem downtimes for replacement or repair exceed desirable downtimes, the subsystem will include backup (redundant) operational capability to permit maintenance. Expendable items (filters, etc.) will be replaced on a preplanned, scheduled basis.

7.2 ONBOARD ELECTRONIC MAINTENANCE (STUDY TASK 3)

The objective of this task was to generate recommendations of supporting research and technology activities leading to implementation of a manned electronics maintenance facility for the Space Station. Early in the task it became apparent that attention could not be confined to a central maintenance facility; it was necessary to refocus the task to address implementation of an on-board maintenance capability encompassing in-place as well as centralized maintenance activities. The critical questions are the following:

- What is the optimum allocation of onboard maintenance functions between in-place and centralized maintenance facility locations?

- What is the optimum level of onboard repair (i.e., to line-replaceable unit, subassembly or module, piece part, or circuit element)?

7.2.1 MAINTENANCE CYCLE

In order to place the task in the proper context, a generalized Space Station electronic maintenance cycle is depicted in Figure 7-1.

A convenient place to enter the cycle is with detection of a fault ("In-Place Maintenance" block). The fault is isolated to a Line Replaceable Unit (LRU). The affected subsystem is restored to full capability by replacing the failed LRU with an operable one from spares storage.

The failed LRU is taken to a maintenance facility (assumed for the moment to have a fixed location in the Space Station) where it is first classified as repairable or non-repairable. Classifications will likely be predetermined, and a listing should be retained in the Data Management Subsystem. If the LRU is non-repairable, it is placed in segregated storage. If the LRU is repairable on board, the fault is further isolated to the failed Shop Replaceable Assembly (SRA). The LRU is then repaired by replacing the failed SRA with one from spares storage. The repaired LRU is then calibrated (if necessary), and its operation verified before it is placed in spares storage.

Logistics requirements (replacement LRUs and SRAs needed) are transmitted to ground-based logistics support functions by RF communications and/or Space Shuttle. Failed units are taken away from and replacement units are delivered to the Space Station by the Space Shuttle.

7.2.2 SUMMARY OF RESULTS

The study confirmed and emphasized the necessity of onboard maintenance for any manned mission of any complexity and duration measured in months (up to 10 years for Space Station). Formulation of recommendations for implementing such a capability required consideration of other topics first, and achievement of certain interim results. The principal conclusions of this study task are summarized below. The analyses leading to them are explained in the Task 3 Final Report.

- Prior studies and developments of in-space maintenance have emphasized justification of first-level (in-place) maintenance, fasteners, and tools for space application and human factors criteria. Much less attention has been devoted to test equipment, maintenance training, or definition of shop level maintenance requirements.

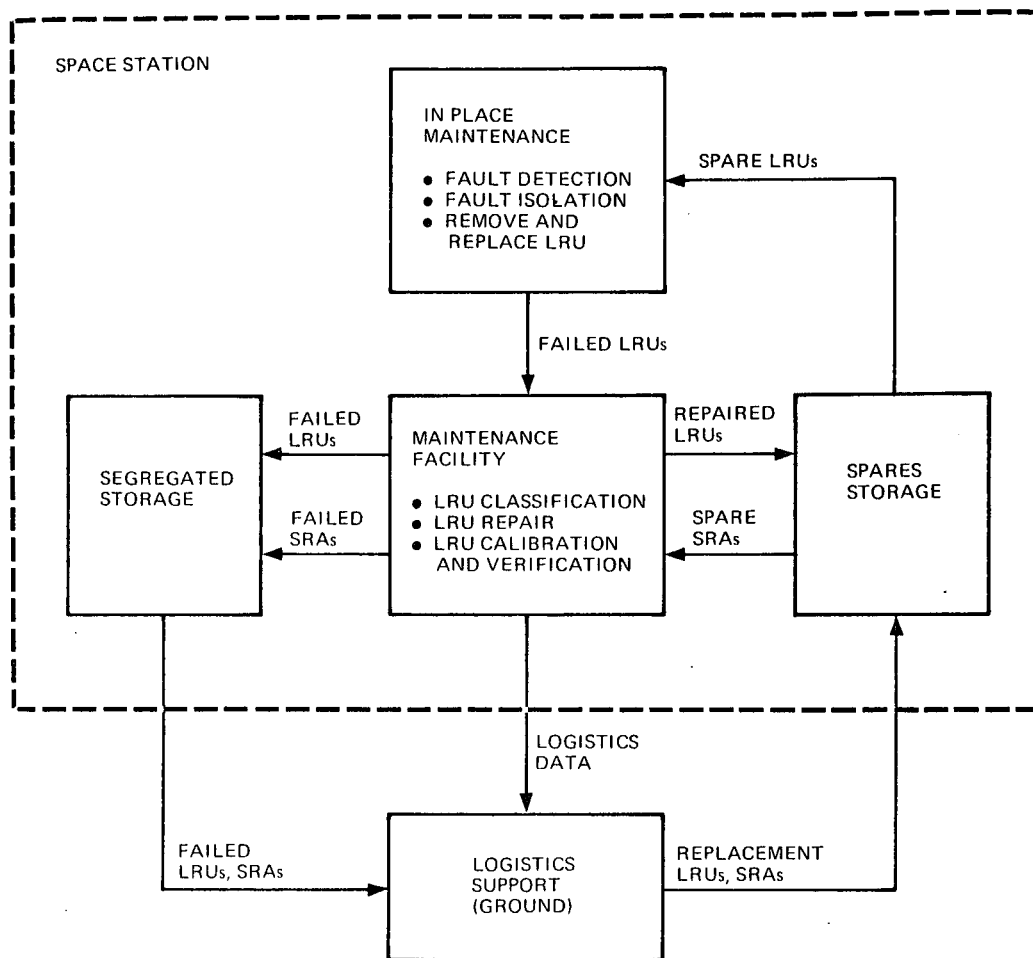


Figure 7-1. Space Station Maintenance Cycle

- The baseline subsystem descriptions, checkout requirements analysis, and software requirements analysis indicate that approximately 60 percent of all faults (over a long period) can be isolated to the failed LRU automatically under software control, without crew intervention. In an additional 27 percent of failure cases, fault isolation to one LRU can be achieved by the crew using the onboard Data Management System as a tool. In the remaining failure cases, additional fault isolation capabilities are needed. This is a good result for a "first iteration" and can probably be improved considerably with a modest effort to modify stimulus and measurement provisions.
- Crew involvement in scheduled and unscheduled maintenance (including participation in fault isolation) is estimated to average 7.2 manhours per week over the total mission time. This estimate is most sensitive to equipment reliability and levels at which onboard repair is performed. It is affected little by the efficiency of automated fault isolation under control of the Data Management Subsystem (DMS).

- The recommended approach to maintenance in the baseline Space Station is in-place removal and replacement of LRUs, without attempts to repair LRUs onboard, if the resupply interval is less than nine months. Onboard spares should be LRUs.
- For long resupply intervals or non-resupplied missions (as in a manned interplanetary mission), in-place maintenance should be by removal and replacement of LRUs. Repair of LRUs should be by removal and replacement of Shop Replaceable Assemblies (SRAs). Onboard spares should be SRAs.
- The Earth-orbital Space Station should include provision for development of onboard maintenance capability and techniques applicable to long duration non-resupplied missions and/or the larger, more complex Space Base.
- The baseline subsystem descriptions are at such a level of detail that precise specification of onboard tools and test equipment is neither feasible nor desirable. Anticipated needs identified qualitatively in the study are: (1) a portable test module to supplement software fault isolation as well as to assist mechanical adjustments and calibrator, (2) hand tools for removal and replacement of electronic assemblies, (3) devices for transporting and positioning spare assemblies, and (4) a central maintenance/repair bench.
- Several tasks have been identified and recommended for future performance, as part of a system study/design program or as separate supporting research and technology tasks. The principal ones deal with (1) development of a portable test assembly, (2) development of a repair/test bench with special provisions for small parts retention and for debris collection, (3) design for accessibility of test points and subassemblies, and (4) devices for transporting equipment within the Space Station.

The foregoing conclusions apply to the Modular Space Station as well as the 33-foot diameter, four-deck configuration.

The results of the study rest upon several assumptions and estimates, derived wherever possible from related experience. The results are not sensitive to small variations of the assumed or estimated values, except for equipment failure rates, which are most influential. Furthermore, it has not been practicable to pursue all trade analyses to include all relevant factors. Nevertheless, the study has generated valid insights into Space Station onboard maintenance and useful visibility of the path to implementation of that capability.